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CHARLES F. MARVIN, Chief

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INTRODUCTION.

The MONTHLY WEATHER REVIEW contains (1) meteorological contributions, and bibliography including seismology; (2) an interpretative summary and charts of the weather of the month in the United States and on the adjacent oceans; and (3) climatological and seismological tables, dealing with the weather and earthquakes of the month.

The contributions are principally as follows: (*a*) Results of the observational or research work in meteorology carried on in the United States or other parts of the world, in the Weather Bureau, at universities, at research institutes, or by individuals; (*b*) abstracts or reviews of important meteorological papers and books; and (*c*) notes. In each issue of the REVIEW abstracts, reviews, and notes are grouped by subjects, roughly, in the following order: General work, observations, and reductions, physical properties of the atmosphere, temperature, pressure, wind, moisture weather; applications of meteorology, climatology, and seismology.

The Weather Bureau desires that the MONTHLY WEATHER REVIEW shall be a medium of publication for contributions within its field, but **the publication of contributions is not to be construed as official approval of the views expressed.**

The partly annotated bibliography of current publications is prepared in the Weather Bureau Library. *Persons or institutions receiving Weather Bureau publications free should send in exchange a copy of anything they may publish bearing upon meteorology, addressed "Library U. S. Weather Bureau, Washington, D. C.,"* in order that the monthly list of current works on meteorology and seismology may be as complete as possible. Similar contributions from others will be welcome. Bibliographies of selected subjects are published from time to time in the REVIEW OR SUPPLEMENTS.

The section of the weather of the month contains (1) an interpretative discussion of the weather of North America and adjacent oceans and some notes on the weather in other parts of the world; (2) details of the weather of the month in the United States; and (3) brief discussions of weather warnings, rivers and floods, and weather and crops. There are illustrative charts. The climatological tables comprise summaries of the weather and excessive precipitation data for about 210 stations in the United States, and summaries of the weather observed at about 30 Canadian stations.

It is hoped that the meteorological data hitherto contributed by numerous independent services will continue as in the past. Our thanks are due especially to the directors and superintendents of the following:

The Meteorological Service of the Dominion of Canada.
Meteorological and Seismological Service of Mexico.
The Meteorological Service of Cuba.
The Meteorological Observatory of Belen College, Habana.
The Government Meteorological Office of Jamaica.
The Meteorological Service of the Azores.
The Meteorological Office, London.
The Danish Meteorological Institute.
The Physical Central Observatory, Petrograd.
The Philippine Weather Bureau.

The seismological tables contain, in a form internationally agreed on, the earthquakes recorded on seismographs in North and Central America. Dispatches on earthquakes felt in all parts of the world are published also.

Since it is important to have as the name of the month appearing on the cover of the REVIEW that of the period covered by the weather discussions and tables rather than that of the month of issue, the REVIEW for a given month does not appear until about the end of the second month following.

SUPPLEMENTS, containing kite observations, and others containing monographs or specialized groups of papers, are published from time to time.

NOTES TO CONTRIBUTORS.

Authors are requested to accompany their papers submitted for publication with a brief opening synopsis. When an article deals with more than one subject—as, for example, a method of measurement, some experimental results and a theory—each subject should be summarized in a *separate paragraph*, with a title which clearly describes it.

When illustrations accompany an article submitted for publication in the MONTHLY WEATHER REVIEW, the places where they should appear in the text should be indicated, and legends or titles for them should be inserted just after the end of the article. As far as practicable the illustrations when accompanied by their legends should be self-explanatory—i. e., the data on them should leave no doubt of what they are intended to convey.

BACK NUMBERS OF THE REVIEW WANTED.

The Weather Bureau has not enough of the following numbers of the MONTHLY WEATHER REVIEW to meet even urgent requests for filling up files at institutions where the REVIEW is constantly being referred to. The return of any of these or of any 1919 or 1920 issues, especially November, 1919, will be greatly appreciated. The attached addressed franked slip may be used for this purpose, or one may be had on application to the Chief, U. S. Weather Bureau, Washington, D. C.

1914: January, February, March, April, September, October, December.
1915: May, June, July, August.
1916: January, August.
1917: June.
1918: February, September.
1919: Any issue, especially November
1920: Any issue, especially January.

SUPPLEMENT, No. 3.

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CHARLES F. BROOKS, Editor.

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THE LAW OF THE GEOIDAL SLOPE AND FALLACIES IN DYNAMIC METEOROLOGY.

By CHARLES F. MARVIN, Chief U. S. Weather Bureau.

[Washington, D. C., Nov. 10, 1920.]

CONTENTS.

SYNOPSIS.

The action of gravity upon bodies moving over a rotating globe is expressed in two wholly independent inertia reactions. One of these has long been known and dignified by a specific title, *the law of equal areas*. Its action in the dynamics of the atmosphere has been fully discussed, even exploited, by practically all writers on the subject. The other reaction has also long been known, but strangely enough has never been christened. Nameless and neglected, the important part it plays in controlling the motions of the air has been overlooked and misunderstood, or even ascribed to friction and other actions, with the result that serious fallacies have been introduced in many textbooks and writings both by the popular authors and even the mathematicians.

The present paper aims to clear away these mistakes and proposes that the neglected principle be dignified by the name of *the law of the geoidal slope*.

The two actions are inseparable, simultaneous in their operation, not directly antagonistic, but coordinate and complementary. Their action on a body in frictionless motion on a rotating globe is analyzed and made clear.

The general motions of the atmosphere are briefly discussed as steady motions under forces balanced against resistances, and the principal equations of motion are given for cyclonic, anticyclonic, and parallel systems of isobars, including a table of gradient winds for different latitudes and conditions.

Numerous quotations from both popular and mathematical writers are submitted, accompanied by notes clearly showing the errors herein claimed to exist.

The crucial question at issue is submitted to be: What is the nature of the frictionless circulation of the air of a polar hemisphere assumed to be warm at the equator and cold at the poles? A rational answer to this question is offered in which the irreconcilable differences between the frictionless polar cyclone of the mathematicians and a rational polar cyclone derived from the equations of the gradient winds are clearly exhibited.

The basic conditions which underlie the general circulation of the atmosphere are stated in 12 fundamental principles.

HISTORICAL.

Many standard textbooks on Meteorology when treating of the motions of the atmosphere call attention to the superhurricane winds which are called for by the operation of the law of equal areas and claim these inconceivable velocities are prevented in nature by atmospheric friction, convection, turbulence, etc.

It appears W. M. Davis was the first to call attention to the fallacy involved in such representations (Elementary Meteorology, p. 103), which he explained by stating that the deflective influence of the earth's rotation changes the direction *only* of a freely moving body and can produce no effect on the velocity. He adds, "If a body were given a velocity of 25 miles an hour to the south when in latitude 30 N. and was supposed to move without friction over a level surface, it would continue to move at the same moderate rate whatever latitude it reached."

As statements of facts, Davis's representations are perfectly correct, but as an explanation of a fallacy they are insufficient, because the operation of the law of equal areas is one thing, while the action of the deflective influence of the earth's rotation on bodies in free frictionless motion is an entirely separate and different thing. These two influences are just as separate and different in their characteristics and actions, to use an imperfect analogy, as water is different from one of its constituents, oxygen or hydrogen.

In the present state of this subject no valid representations appear to have yet been made to show just why it is the actual motions of the atmosphere are gentle and beneficent whereas the theory of equal areas, which can not be questioned, calls for winds of superhurricane force and inconceivable velocities.

Mr. H. W. Clough, in an article in this REVIEW (Aug., 1920, 48: 463), enlarges upon Davis's explanation of this friction fallacy, and explains it by resort to the deflective influence of the earth's rotation. These efforts, however, do not constitute a sufficient explanation of the fallacy or serve to account for the errors in the mathematical writings of Ferrel, Bigelow, and others.

Any careful reader of either Davis's or Clough's remarks on the subject must wonder what discrimination should be made between the law of equal areas and the deflective influence of the earth's rotation, or he must infer that both Davis and Clough regarded these two concepts as more or less identical. In fact, the whole fallacy has arisen and spread chiefly because writers of high authority have failed to adequately recognize the distinction and the relation.

With full acknowledgment to the authors mentioned, the writer believes the present paper sets forth and offers the first correct explanation of serious fundamental errors which have appeared in nearly all meteorological writings, both popular and mathematical, during the past 60 years.

In order to present our subject matter in a direct and logical manner, it will be necessary to review in the briefest possible way what is already well known, but not always consistently applied relative to—(1) the law of the constancy of momentum, (2) the properties of a gioidal surface, (3) the deflective influence of the earth's rotation, its effects on bodies in frictionless motion and its relations to (1) and (2).

Readers who are already familiar with the fundamental principles of dynamics governing the motions of the atmosphere may pass over Sections I to V, inclusive, and read at once the criticisms in Section VI.

I. The Law of the Constancy of Momentum.

This basic law of matter is of universal application and its demands must of course be satisfied in all cases. Nevertheless, great care must be observed as to how the law is applied to the motions of the atmosphere and of bodies moving freely over any rotating globe.

The law simply states the fact of nature that unless acted upon by extraneous forces the *momentum* of a given mass in motion remains constant. If an extraneous central force causes the body to move about a point or axis then the *moment of momentum* remains constant.

Applied to motions on the earth's surface or any rotating globe the equation, stating this law, may be written:

$$Er = E_1 r_1 \text{ or } E \cos \varphi = E_1 \cos \varphi_1 = \frac{\text{constant}}{R} \qquad (1)$$

in which r and r_1 are the respective distances of the body from the axis of rotation on a globe with mean radius R. E_1 then becomes the component of velocity in longitude (eastward or westward) of a body on reaching the latitude φ_1 after leaving the latitude φ where its motion in longitude was E.

Equation (1) suggests the origin of the name "the law of equal areas," because for elemental motions the products like Er in any case of motion around a point is twice the area swept over in a small unit of time by the vector r, and in the case of rotation about an axis the product $E \cos \varphi$ for elementary motions represents, for unit radius, twice the area swept over by the vector from the moving body to the axis of rotation *when said area is projected on the plane of the equator.* By equation (1) these areas are equal, each to each, whence the name.

It will be noticed equation (1) is wholly independent of the velocity by which the change of latitude occurs. A given change of latitude may occur in a minute or a year and cause exactly the same change in the eastward (or westward) velocity of the body if no other forces are in action.

The rotative velocity of a particle at the earth's surface in miles per hour at any latitude φ is

$$E = 1038.7 \cos \varphi \qquad (2)$$

The table below gives values computed from equations (1) and (2) for a body assumed to move without friction exactly poleward from rest at the equator.

TABLE 1.—*Velocities on the rotating earth satisfying the law of equal areas.*

[Velocities in miles per hour.]

Latitude.	Eastward surface velocity. E.	Eastward velocity of body on arrival.	Eastward velocity of body over ground.	Ferrel[1] (+ eastward, − westward).
	2	3	4	5
° ′				
0 00	1,039	1,039	0	− 346
10 00	1,023	1,055	32	− 320
20 00	976	1,105	129	− 239
30 00	900	1,199	299	− 100
35 16	848	1,115	377	0
40 00	796	1,356	560	+ 108
50 00	668	1,616	948	+ 410
60 00	519	2,077	1,558	+ 865
70 00	355	3,037	2,682	+1,669
80 00	180	5,981	5,801	+3,807
90 00	0	∞	∞	+ ∞

[1] Velocities satisfying Ferrel's equation for frictionless circumpolar cyclone with maximum pressure at latitude 35° 16′. See discussion in later section on citations from mathematicians.

Many textbooks represent that the impossible velocities in column 4 would occur in nature if it were not for friction and various internal wastes of kinetic energy. These teachings are erroneous, because bodies can not be moved over the earth's surface subject *only* to the law of equal areas. The computations above are applicable to a body on the earth only on the assumption that the downward pull of gravity *as it acts on the moving body* is exactly perpendicular to the smooth geoid. This can not be the case, and herein lies the very root of the fallacy.

The popular writers especially seem to have exploited the operation of the law of equal areas and emphasized the superhurricane velocities changes of latitude would require if not restrained by friction. In such teachings the operation of what we now call the law of the geoidal slope has not been adequately recognized. This is the more surprising because it is also clearly set out in many, sometimes even in the same textbooks and writings, that bodies in frictionless motion over a rotating globe follow a curved path *without change of velocity.* Davis says: "A body once set in motion under these conditions would continue moving forever, always changing its direction but never its velocity." [2]

All the facts of the matter were made clear by Ferrel in 1858, but they have not been consistently applied in many cases, even by Ferrel himself, and therefore emphasis must be placed upon the neglected details, the principle of the geoidal slope.

II. The Law of the Geoidal Slope.

It has long been taught and recognized that the figure of the earth is not truly spherical, but that because of the revolution about its axis the form is geoidal, which by definition is a form the surface of which at each point is perpendicular to the plumb line at that place. This condition would be fully satisfied if the earth's surface were entirely of water or other liquid.

General statement of the law.—The properties of a geoidal surface, assumed to rotate from the west to the east, may be comprehended in a single statement as follows: *A geoidal surface is a neutral or horizontal surface only for bodies at rest upon it. That is, gravity is powerless to set up any lateral motions among such bodies. The surface slopes toward the equator for every body having a relative motion eastward and toward the pole for every body with a motion westward. A component of the force of gravity pulls the moving bodies down the slopes.*

This principle follows directly from the action of gravity on a rotating yielding globe. Assuming homogeneity, the figure of equilibrium will be spherical if the globe is at rest. If rotating about an axis through the center of mass the centrifugal reaction gives rise to a component of gravity which acts tangent to the surface and toward the equator. This force causes flattening at the poles and bulging toward the equator. The amounts will be nicely adjusted to the speed of rotation, and for equilibrium the resultant downward pull of gravity, represented in direction by the plumb line, will be just perpendicular to the surface at each place.

Assuming that the globe revolves from the west to the east, then any body which moves eastward over the surface will actually move more rapidly around the axis

[2] Davis, Wm. M.: Elementary Meteorology, p. 104. See also Sprung: On the paths of particles moving freely on the rotating surface of the earth, etc.; English translation by Abbe and Russel, Smith. Misc. Coll., vol. 51, No. 4. Whipple: The motion of a particle on a smooth rotating globe, Phil. Mag., vol. 33, 6th series, 1917, p. 457.

than the geoid itself, and for this body the equator is not bulged out enough—that is, the geoid slopes downward toward the equator. Just the reverse is true if the body moves to the westward, because it is then revolving more slowly than the geoid about the axis, and the equator is then bulged too much.

It is highly important in the study of the general circulation of the atmosphere that the student form a clear mental picture of the real terrestrial conditions brought about by the operations of this geoidal law.

For all the winds of the globe moving eastwardly, the surface of the earth is like a trough with its axis or bottom line coinciding with the equator and its lateral slopes rising higher and more steeply with latitude and the eastward velocity. A component of the force of

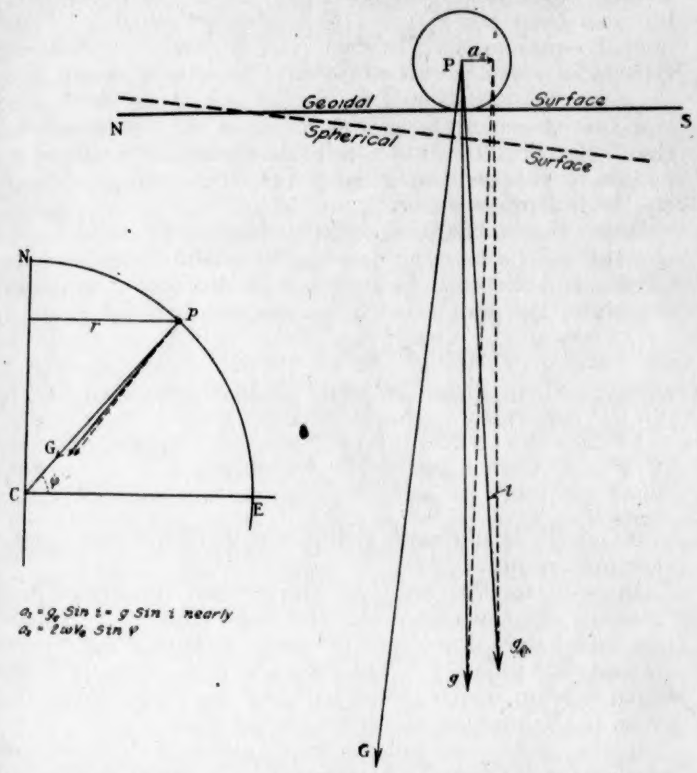

FIG. 1.—Action of gravity on matter on a rotating globe. For globe at rest, surface is spherical and plumb line extended passes through center. In rotation, surface is geoidal, plumb line Pg passes beside center, and force is smaller. If body moves eastward, plumb line inclined farther from center Pg_e and component a_s pulls body down geoidal slope.

$$a_s = g_e \sin i = g \sin i \text{ nearly} = 2\omega\ V_e \sin\varphi$$

gravity continually drives such winds down the slope toward the equator.

On the other hand, the equator is like a ridge or a geoidal divide for all winds moving to the westward. The hemispheres in this case are bowl-like forms to westwardly moving masses of air which are therefore urged poleward by a component of gravity acting down the slopes.

Students who are even fairly acquainted with meterorological literature, will recognize that there is little if anything essentially new in the fundamental principles involved in the foregoing statements.[3] These truths have long been known but the novelty of the present effort is the emphasis laid upon the fact that the surface of the earth in general is an up-hill surface in one sense to every moving body upon it, except when the motion is exactly along a meridian or the equator. There is in action at all times on such bodies, therefore, a component of gravity drawing them toward the equator or the poles according to the latitude and the relative velocity in longitude. The relation of this matter to the operation of the law of equal areas as applied to the motions of the atmosphere in latitude, has long been seriously neglected or overlooked.

It is the pull of gravity down the geoidal slopes, not friction, which prevents the superhurricane velocities exploited in the textbooks.

With the foregoing brief discussion of (1) the law of equal areas and (2) the law of the geoidal slope, it will be easy to understand the combination of their effects into the well-known deflective influence of earth's rotation.[4]

III. THE DEFLECTIVE INFLUENCE OF THE EARTH'S ROTATION.

It is very suggestive of the profound obscurity of this subject to recognize that it has occupied the attention of scientists for fully 200 years; nevertheless several of the most recent writings contain erroneous statements concerning its application in both meteorology and astronomy.

Two rotation effects.—It must not be forgotten, moreover, that more than 60 years ago Wm. Ferrel[5] without emphasizing in any way the parts played separately by the two components was, however, the first fully to analyze and evaluate both influences of rotation as two wholly separate and independent inertia reactions. The operation of these require (*a*) that changes in latitude must be accompanied by accelerations in longitude to satisfy the demands of the law of equal areas; and (*b*) that changes in longitude must be accompanied by forces in the meridians arising from a tangential component of gravity which it is now proposed to comprehend under the name of *the law of the geoidal slope*.

Ferrel also showed that the resultant of these two coordinate and simultaneous influences was entirely passive in its character, because it always acted exactly perpendicular to the line of motion of any body and therefore could not change the velocity but always changed the direction of motion.

The value of the force on a mass of m grams at latitude φ, moving in any direction at a velocity V centimeters per second is:

$$f = 2\omega m\ V \sin\varphi \text{ ---- Earth's deflective influence} \quad (3)$$

in which $\omega = \dfrac{2\pi}{86164}$ = angular velocity per second of the rotation of the earth on its axis.

Since the possible changes in latitude, φ, are small for ordinary values of the velocity, V, along the path the term $\sin\varphi$ is practically constant for any one locality, hence f is proportional to V. When this is the only deflecting force in operation the radius of curvature of the path is given by the equation:

$$r = \frac{V}{2\omega \sin\varphi} \quad (4)$$

and r is also constant for any one locality, and therefore the path of the body (if not too close to the equator) will be nearly a circle not quite closed on its western side.

[3] Ferrel: Professional Papers, Sign. Serv. No. 8, p. 48, sec. 100; Popular Treatise on Winds, p. 110, sec. 76. Davis: Elementary Meteorology, footnote, p. 115.

[4] For a full explanation, see MONTHLY WEATHER REVIEW, September, 1916, 43, 506.

[5] Ferrel, Wm.: Professional Papers No. 8, Signal Service, Annual Report, Chief Signal Officer, 1885, pt. 2, A Popular Treatise on Winds, ch. 2.

This path will be traversed at a uniform velocity and the time of rotation is easily seen to be:

$$T=\frac{2\pi r}{V}=\frac{\pi}{\omega \sin \varphi}$$

which is wholly independent of the velocity of the body. If T is measured in siderial hours $\omega=\frac{2\pi}{24}$ and $T=\frac{12}{\sin \varphi}$. Near the poles, where $\sin \varphi$ is sensibly unity, the body completes the circuit of its orbit in the time of half a rotation of the earth. In fact, at any latitude the angular change in the direction of motion of any freely moving body is double the angular turning of the ground by the earth's rotation.

The parts played by the two components of the deflective influence are clearly brought out in the discussion of figure 2.

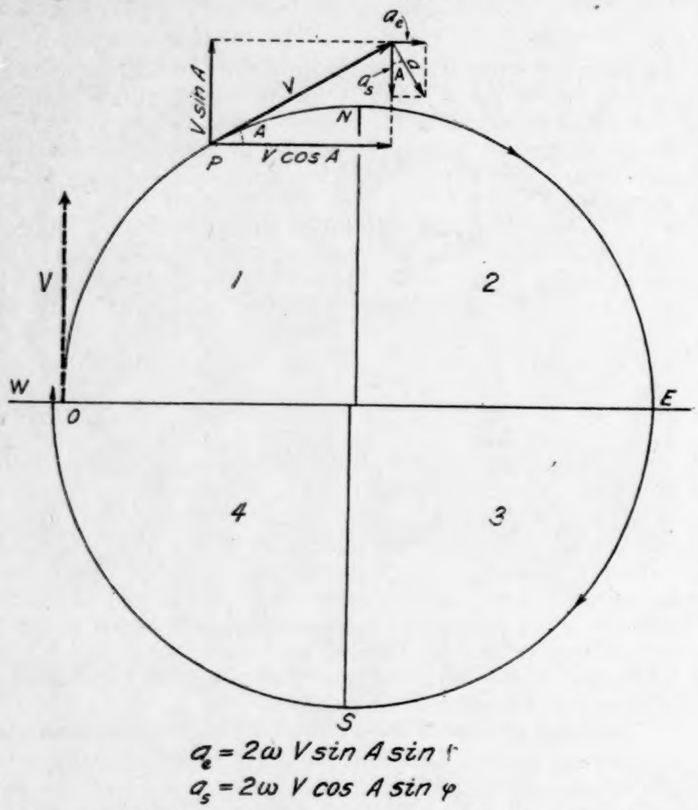

FIG. 2.—Path of body in frictionless motion at moderate velocity in Northern Hemisphere.

The case of frictionless motion.

At P the body will be moving at an angle A to the west-east line. The north component, $V \sin A$, and the east component, $V \cos A$, will give rise respectively to the accelerations eastward—

$a_e = 2\ \omega\ V \sin A \sin \varphi$ ----angular momentum effect and southward,

$a_s = 2\ \omega\ V \cos A \sin \varphi$ ----slope effect.

This southward acceleration a_s (or northward as the case may require) is the extraneous force which prevents the free operation of the law of equal areas. *Without* the slope effect, or acceleration a_s, figure 2, any body set moving northward in a frictionless manner would continue to move northward indefinitely. If started at the equator it would acquire the enormous velocities eastward given in Table 1, column 4. *With* the acceleration a_s the northward velocity is continuously checked until reduced to zero. Practically all writers on this subject up to the present time have disregarded the important part the acceleration a_s plays in terrestrial motions and that a_s and a_e are complementary and inseparable in their action. *Furthermore, the law of the conservation of momentum is satisfied at every point of the motion but without any change in the velocity of the body over the ground.*

Resuming the explanation of figure 2 and tracing the action of the accelerations a_e and a_s through the four quadrants of motion, it is plain that the momentum effect (the law of equal areas) has, at P given the body the eastward velocity $V \cos A$. At the same time the slope effect has reduced the initial northward velocity from V to $V \sin A$, and will presently completely destroy *all* the northward velocity. This is not lost, however, but has been transformed to eastward velocity by the law of equal areas. In fact, the *eastward or westward velocity at every point of the orbit is exactly that appropriate to the latitude and the initial velocity.* The law of equal areas accomplishes this control. If it were not for the slope effect the law of equal areas would produce indefinitely greater and greater velocities with each successive latitude reached.

When the body has reached its highest latitude northward it will be running due east on a southward sloping hillside and therefore be subject to a downhill component of gravity the amount of which is given by the equation:

$$g \sin \alpha = a_s = 2\ \omega\ V_e \sin \varphi$$

whence the inclination of the geoidal slope can be obtained from the equation:

$$\sin \alpha = \frac{2\ \omega\ V_e \sin \varphi}{g} \tag{7}$$

in which V_e is the eastward or westward velocity as the case may require.

As soon as the body in the second quadrant runs downhill (southward) under the slope effect the momentum effect cuts down and presently completely destroys *all* eastward velocity. The body has now returned to the latitude from which it started, and the slope effect has given it the maximum velocity southward.

In the third quadrant the momentum effect must give accelerated *westward* velocities and the body finds itself running uphill on a geoidal slope, only to come to rest at the highest point it can attain (the lowest latitude), thence turning it runs down the slope in the fourth quadrant of its orbit, which returns to a point a little westward of the starting point as indicated. This hiatus is due to the variations in $\sin \varphi$ along the path and the corresponding changes in curvature.

From this analysis it is clearly seen that in general every body moving freely and in the most frictionless manner conceivable is nevertheless constantly controlled by the two contending influences, the latitude effect and the slope effect. The law of equal areas is perfectly valid, and if acting alone and in so far as changes of latitude are concerned, would create just such velocities in longitude as have been ascribed to it. However, no such influence is free to act, or, more correctly, Nature opposes and nullifies one accelerating cause by another, the one the well-known law of equal areas; the other the law of the geoidal slope. The two are inseparably associated, simultaneous in their operation, not antagonistic of each other, but coordinate and complementary.

Thus it is seen there is no need to invoke friction and other wastes of energy to explain away the incredible velocities in longitude due to the operation of the law of

equal areas. These velocities are automatically controlled by gravity itself acting directly upon the masses in motion as they run upon the geoidal slopes created by the motions and instantly adjusted in steepness to the requirements of the case by the momentary velocities in longitude.

Thus far we have considered only frictionless motions at a uniform velocity due to an initial impulse. We must next consider in the briefest possible manner the steady motions of the air under constantly acting pressure gradients with or without friction. We need not consider how the gradients or the resistances are produced or maintained, but the results attained will aid in readily understanding the fallacies to be shown in the quotations which will be given later.

IV. Steady Motions Under Forces Balanced Against Resistances.

Pressure gradients.—The immediate forces which produce the general motions of the atmosphere arise by virtue of, and are measured by, pressure gradients. Such gradients in air and other fluids are gravity reactions and in the grand case of the whole atmosphere the permanent gradients depend chiefly upon the *great contrasts of temperature* which are perpetually maintained by the unequal heating of the earth's surface by the sun, which, in conjunction with the continuous loss of heat by terrestrial radiation, cause the perpetual warmth of the Tropics and the extreme cold of the polar regions.

Resistances.—Convections of all kinds, turbulence, and eddy motions probably constitute by far the greatest resistances to atmospheric motions, but these are augmented by surface frictions and the flow over and around obstacles, and finally by the internal viscosity, which, however, becomes vanishingly small in the upper atmosphere. In fact, it is difficult to conceive of any serious resistance to motions in the higher strata, especially where convection is small or absent as in the stratosphere. Nevertheless, all these influences operate to retard or destroy motions. The great gyratory system of flow of cyclones, for example, all great and small motions of the air would soon run down and stop if not continuously maintained by an extraneous force or gradient. A part of the gradients which sustain motions is constantly expended in overcoming resistances and the final state of steady motion [6] is one in which the winds flow steadily *across* the isobars at a small angle. While this action resulting from resistance causes only a very small loss of *velocity*, 1 or 2 per cent, perhaps, below a state of frictionless flow, it will be accompanied by a very important and relatively considerable deflection of the winds amounting to 10° to 20° or more from the theoretical *direction*.

Motions near the Equator.—The deflective influence of the earth's rotation is zero at the Equator and very feeble for distances of several degrees of latitude either side thereof.[7] Within this wide equatorial belt motions of the air are of the simplest possible character, elsewhere the deflective influence is a more and more powerful disturbing factor attaining its maximum value at the poles. For present purposes it suffices to consider only horizontal pressure gradients and motions such as might occur over the oceans, because all winds are chiefly parallel to the ground, which is nearly horizontal in all but a few cases.

[6] The term "steady motion" with the same meaning as herein seems to have been introduced by Oberbeck, Mech. Earth's Atmos. Abbe. Smith. Miscl. Coll. 843, p. 177.

[7] The tropical hurricane has its infrequent and mysterious origin on the borders of the region here considered. This phenomenon, however, is an entity in itself, but it plays no part in the present considerations. The mathematical basis for the dreaded velocities of its wind systems is, however, completely understood and expressed by equation (15) for horizontal motions.

Imagine a small portion of free air, a cubic centimeter of air, for example (fig. 3) in a region where the pressure is high at the left and low at the right, as suggested by the isobars B_1 B_2 B_3, etc. Each face of the cube is subjected to a pressure over the whole surface which may be represented by the several forces $p_1, p_2, \ldots p_6$. In addition, the cube has mass and is pulled downward by gravity, represented by the relatively small force $W = \rho g$, in which ρ = the mass of the cubic centimeter of air under the given conditions, and g is the acceleration of gravity. Now, since the pressure is assumed to diminish steadily from left to right, p_1 will be greater than p_2, and the cube will be urged toward the right by a force $\delta p = p_1 - p_2$. Since we assume there is no change in pressure in the direction parallel to the isobars, then the two pressures p_5 and p_6 are equal and neutralize each other so far as motion of the cube is concerned, and may therefore be disregarded. Finally, p_4 must be greater than p_3 by just enough to make

$$p_4 = p_3 + \rho g \qquad (8)$$

which is the equation of forces in the vertical. If p_4 is too great, the body *will be pushed vertically upward*, or

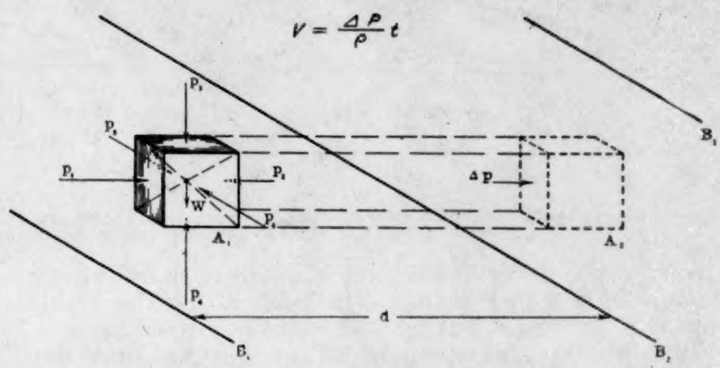

FIG. 3.—Forces resulting from atmospheric pressure and gravity upon a cube (1 c. c.) of air, weight W, and causing motion in the direction A_1 to A_2.

as it is commonly but less correctly stated, "it will ascend." If p_4 is not great enough, the body of air is said to be heavy, that is, it is insufficiently supported by the pressure of the surrounding medium, and it descends or falls under gravity.

We here assume the forces in the vertical are in equilibrium and may therefore be disregarded. Assuming further that our cube of air is not acted upon by any other forces than surface pressures, the excess force δp must move the cube down the gradient from a place of higher to a place of lower pressure, as from A_1 to A_2.

The force δp in this case is the pressure gradient and may be found from the spacing of the isobars by the following:

> RULE.—*The pressure gradient at a given place may be found from a weather map of the locality in question by dividing the difference in pressure between two isobars by their perpendicular distance apart.*

whence the equation:

$$\delta p = \frac{p_1 - p_2}{1} = \frac{B_1 - B_2}{d} K \qquad (9)$$

in which K is a constant depending upon the units in which the isobars B and the distance between them, d, are expressed.

It will be instructive to calculate the velocity which a portion of air will acquire if free to move in a frictionless manner and acted upon by no other force than the pressure gradient δp.

Take a gradient of 4 millibars (4,000 dynes) per 100 kilometers (0.1 inch per 53 miles). While comparatively steep, nevertheless such a gradient is frequently shown on weather maps. The mass of a cubic centimeter of air varies, but may be taken at $\rho = .0012$ grams. From well-known equations of motion we have for velocity at end of t seconds

$$v = \frac{\delta p}{\rho} t \tag{10}$$

or at the end of one hour

$$v = 26.8 \text{ miles per hour.} \tag{11}$$

Hence air starting from rest and moving under the conditions assumed, gains velocity at the rate of 26.8 miles per hour. The distance traversed in the first hour would be 13.4 miles.[8]

Within the equatorial belt where the deflective influence is very small the motions of the air are almost strictly in accord with equation (10) and figure 3. Friction slows down the motion somewhat, but in all cases the air flows almost directly from the place of high to the place of low pressure. Owing to the absence of any causes adequate to produce and maintain marked contrasts, widespread uniformity of temperature and pressure is the ruling characteristic of this belt, accompanied by direct flow and easy intermixture of differing air masses, so that calms and light winds only are found, except in certain regions, as the Indian Ocean, where the monsoons prevail.

The surface winds, at least of the equatorial belt, are probably not true steady motions against balanced forces. This will be made more obvious in a later section treating of gradient winds for the globe.

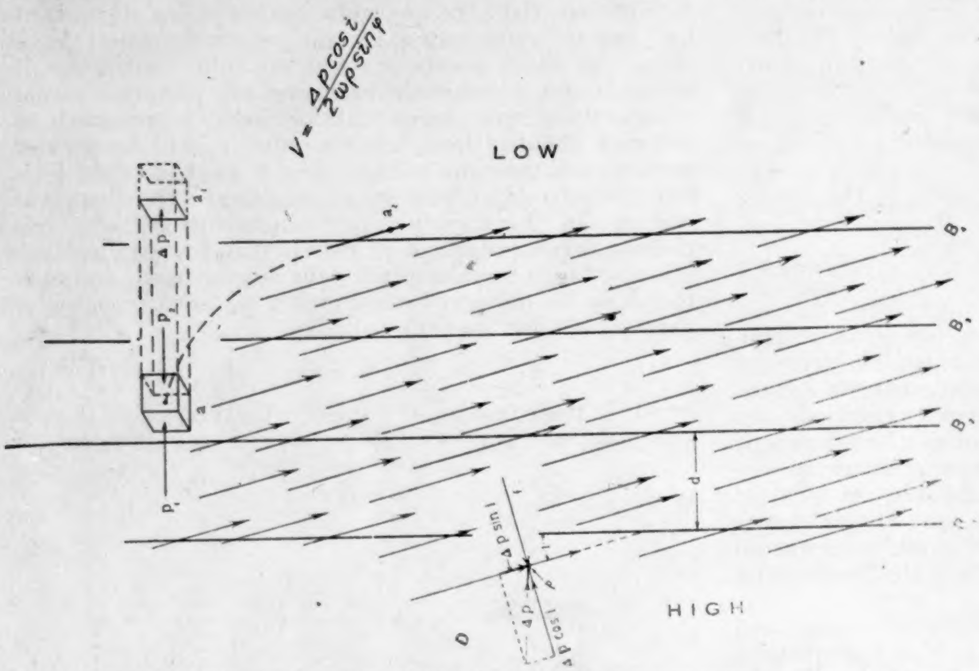

FIG. 4.—Diagram showing equilibrium motion of winds in straight lines under some frictional resistance for a pressure system represented by parallel straight-line isobars.

Motions controlled by deflective influence.—It was shown in figure 3 that a unit volume of air acted upon only by a pressure gradient δP would move simply down the gradient as from A_1 to A_2. (See also fig. 4.) We know, however, that no sooner is air set in motion than it is deflected to the right) or the left in the Southern Hemisphere) by the influence of the earth's rotation. Instead, therefore, of moving from a to a_1, figure 4, as one would be led to expect, the air will follow some such course as shown by the dotted line a to a_2. We can not trace the beginnings of atmospheric motions in any actual case, or follow the intermediate steps up to the attainment of steady uniform motion.[9] We can, however, clearly define the condition of steady motion such as shown in figure 4, which is intended to represent an extended system of straight and parallel isobars, B_1, B_2, etc., corresponding to high pressure to the left and low pressure to the right. Under such conditions the whole mass of air would flow in a steady stream along straight and parallel lines, such as indicated by the arrows, inclined at a slight angle across the isobars.[10]

The equation of this steady motion is easily deduced from the diagram of forces at D, figure 4, representing a unit volume of air. The pressure gradient δP is shown resolved into two components.

$\delta p \sin i$, acts parallel to the direction of motion and overcomes frictional resistance.

$\delta p \cos i$, acts normal to the motion and nullifies the earth's deflective influence.

That is,

$$\delta p \cos i = f = 2\,\omega\,\rho\,V \sin\varphi$$

$$V = \frac{\delta p \cos i}{2\,\omega\,\rho \sin\varphi.} \tag{12}$$

Equation (12) gives the velocity of the "steady wind" for the gradient δp, the wind crosses the isobars at the angle i. If the friction diminishes, the parallel component, $\delta p \sin i$ will accelerate the speed, but f will also then increase and will further deflect the line of motion and diminish i, so that, clearly, when friction is wholly absent the angle i becomes zero; that is, the flow is strictly parallel to the isobars and we have the special equation for frictionless motion in a straight line (a great circle).

$$\delta p = 2\,\omega\,\rho\,V \sin\varphi$$

$$V = \frac{\delta p}{2\,\rho\,\omega \sin\varphi.} \tag{13}$$

Equation (13) gives the velocity of the well-known gradient wind for straight isobars.

Steady winds and gradient winds.—The system of winds shown in figure 4 is intended to represent continuous

[8] Gold has given a much more extended treatment of this in Proc. Roy. Soc., vol. 80, May 25, 1908; also Mechanics Earth's Atmosphere, Abbe, Smith. Misc. Coll., vol. 51, No. 4.

[9] Shaw, Sir Napier: Manual of Meteorology, Pt. IV, p. 3, and Barometer Manual for use of Seamen. Metl. Off. 61, 1919, p. 8 et seq.

[10] Strictly speaking, such a system of parallel isobars must be a system of great circles having a common pole and therefore converging in both directions, but the amount of this convergence, within even an extended region such as here considered, is insignificant, and no appreciable error, therefore, is involved if we assume such isobars to be parallel.

motion at a uniform velocity under a uniform pressure gradient and a constant state of friction. It is entirely incidental that the isobars are straight instead of curved lines. There are two points to be emphasized: (*a*) that all the forces acting are completely balanced; (*b*) that one of these forces is friction, to overcome which the component of the gradient $\delta p \sin i$ must act directly along the path of the wind, which must be inclined across the isobars at the angle i. This example furnishes a complete case of steady winds under balanced forces. The active force of the pressure gradient δp is split up into two components; one, $\delta p \cos i$, balances the passive

winds under balanced forces *when all friction is excluded*. By this usage, all natural winds when forces are balanced, are designated *steady winds* because friction is always present and the winds then blow across the isobars. True *gradient winds* flow strictly parallel to the isobars under balanced forces, friction being zero, a state never attainable in nature.

The steady winds of the globe.—The motions of figure 4 represent by far the greater portion of the permanent steady winds of the globe, because, especially over the ocean and away from the immediate proximity of cyclonic and anticyclonic centers, the isobars are long

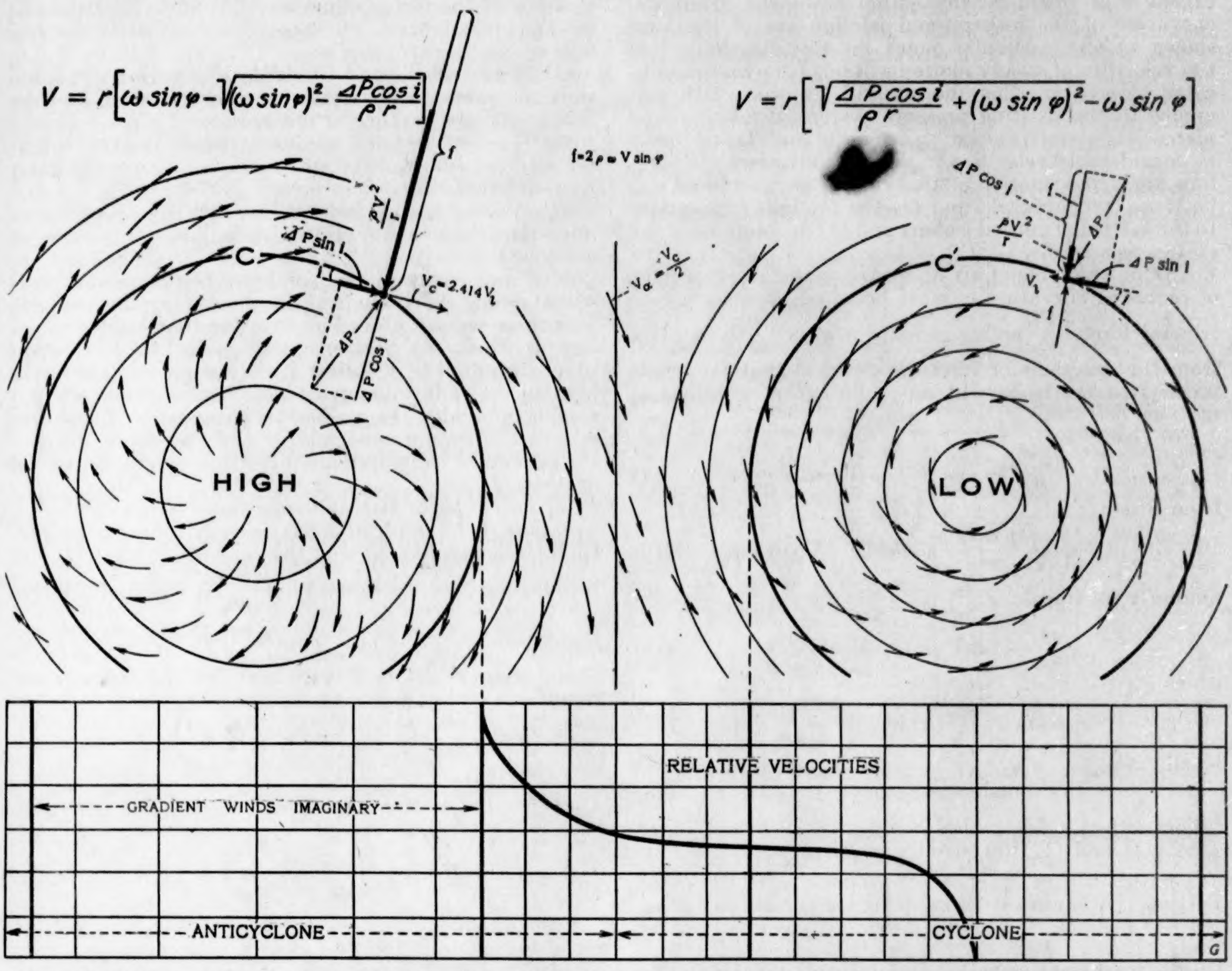

FIG. 5.—Idealized diagram to show steady motions of winds within and between highs and lows. For clearness winds are shown crossing the isobars at the appreciable angle i, due to friction. In the HIGH, C indicates the isobar with critical curvature. C' is an isobar of same curvature in the LOW. The active force causing all the motions is the pressure gradient Δp. Friction is overcome by the component of the gradient $\Delta p \sin i$. A force $\frac{\rho v^2}{r}$ is required to give the requisite curvature to the path of the winds; f is the deflective influence, which is balanced by the component of the gradient, $\Delta p \cos i$. All diagrams of forces are carefully to scale for a uniform gradient over the diagram. The lower portion shows the zone of imaginary gradient winds in the High, and the relative velocities from the critical isobar of the high to the center of the low under uniform gradient.

action of the deflective influence; the other, $\delta p \sin i$, overcomes the frictional restraints. The resulting *steady winds* blow *across* the isobars at an angle, i, which in the free air especially will be small.

A number of meteorologists are not careful enough in the use of terms and call any winds under balanced forces *gradient winds*. The writer strongly urges, in the interests of clearness of language, that the term *gradient wind* be reserved and used only for theroretical

sweeping lines, the curvature of which is entirely secondary. These isobaric lines simply mark out the winding lanes and highways in the atmosphere along which the motions of the air must take place, never flowing quite parallel to the isobars but always cutting across the lines at some angle according to the amount of friction.

Such winds are perfectly free to flow either with or without friction over wide ranges of latitude at velocities moderate or otherwise depending quite entirely

upon the gradient. At every point the motion, or pressure, if motion is constrained, automatically satisfies the requirements of both the latitude and the slope effects, whatever the friction and the velocity.

Steady Winds with Curved Isobars.—Cyclones and anticyclones are well-defined cases of wind systems following strongly curved isobars and the fundamental conditions of steady motions are illustrated in figure 5. A "HIGH," anticyclone, and a "LOW," cyclone, are shown in juxtaposition and with closed isobars drawn as circles only to simplify the presentation. No suggestion is implied that this diagram represents Nature, except that when, in any actual cases, the gradients, curvature of the isobars, and friction are of the kind shown at any particular point on the diagram; then the velocities of steady motion will be of the nature indicated. Moreover, this motion will be that with reference to the existing pressure system *at the time and place.* It is well known that Highs and Lows travel at considerable velocities in definite directions. Therefore, the *actual* motion of the winds *over the ground* will be those compounded from (1) the motions appropriate to the system of curved isobars and (2) the motions of the system as a whole.

Any unit volume of air of mass ρ moving over a path of radius of curvature r, must be acted upon by a centripetal force $\frac{\rho V^2}{r}$ acting radially inward [11]. It is plain from the diagrams of forces in figure 5 that for winds inclined to the isobars at an angle i, the equations of motions become:

For LOWS:[12]

$$\frac{\rho V^2}{r} = \delta p \cos i - 2\omega\rho\ V \sin\varphi \qquad (14)$$

from which

$$V = r\left[\sqrt{\frac{\delta p \cos i}{\rho r} + (\omega \sin\varphi)^2} - \omega \sin\varphi\right] \qquad (15)$$

Similarly for HIGHS:

$$\frac{\rho V^2}{r} = 2\omega\rho V \sin\varphi - \delta p \cos i \qquad (16)$$

which gives

$$V = r\left[\omega \sin\varphi - \sqrt{(\omega \sin\varphi)^2 - \frac{\delta p \cos i}{\rho r}}\right] \qquad (17)$$

In all cases,

$$\text{Frictional resistance} = \delta p \sin i \qquad (18)$$

For perfectly frictionless winds $\cos i = 1$ and equations (15) and (17) for strictly gradient winds become:

$$V = r\left[\sqrt{\frac{\delta p}{\rho r} + (\omega \sin\varphi)^2} - \omega \sin\varphi\right] \ldots\ldots \text{cylonic} \qquad (15a)$$

$$V = r\left[\omega \sin\varphi - \sqrt{(\omega \sin\varphi)^2 - \frac{\delta p}{\rho r}}\right] \ldots\ldots \text{anticyclonic} \qquad (17a)$$

When $r = \infty$ both become:

$$V = \frac{\delta p}{2\omega\rho \sin\varphi} \quad (13) \text{ straight isobars.}$$

Figure 5 shows the directions of motions for the Northern Hemisphere, the directions being reversed for the Southern Hemisphere.

[11] The value of r when large should be taken with due regard for the curvature of the earth, but r can never be very accurately determined in practical cases and the consideration of the earth's curvature may generally be disregarded.

[12] Equation (15) may be written with the + sign in the second member for clockwise rotation in the cyclone. J. S. Dines has called attention to this interesting possibility. MONTHLY WEATHER REVIEW, Feb., 1919, 47: 87.

While equations (15) and (17) are basic and fundamental as defining the general steady motions of the atmosphere, *yet diversity of conditions, irregularity of pressure distribution, changes with time before a state of equilibrium is attained, errors in mapping supposed conditions, and other factors combine to make natural winds in particular cases differ widely and frequently from the theoretical deductions herein presented.* It is worth while, however, to develop somewhat fully certain important results based upon assumed ideal conditions, because these will aid greatly in reaching a full comprehension of atmospheric circulation.

A few of the things equations (15) and (17) tell us as to the possibilities of steady atmospheric motions follow:

(1) When the flow is frictionless $i = 0$ and the equations are then the equations for gradient winds and the flow is strictly parallel to the isobars.

(2) When $r = \infty$ both equations reduce to (12) or (13) for straight line isobars and motions, with or without friction, as the case may be.

(3) When δp and friction $= 0$, the equations determine the frictionless motion of a body set in motion at a velocity V.

(4) From equation (15) for lows it appears that notwithstanding diminution of air density as the pressure falls there seems to be no limit to the steepness or intensity to which the pressure gradient in *cyclonic* motion may attain. The velocity V may become indefinitely high as the radius of curvature r becomes smaller and smaller, provided the gradient is sustained. This corresponds to the enormous velocities of the winds found in the funnels of tornadoes and near the centers of tropical cyclones.

(5) In contrast with the conditions shown for LOWS, equation (17) for HIGHS leads to very different results. Gold [13] has pointed out that the value of V from (17) will be imaginary for all values of $\frac{\delta p \cos i}{\rho r}$, which are larger than $\omega^2 \sin^2\varphi$. It is also obvious that when $\frac{\delta p \cos i}{\rho r} = \omega^2 \sin^2\varphi$ the velocity V will have its maximum value which can be shown to be

$$V_c = \frac{\delta p \cos i}{\omega\rho \sin\varphi} \qquad (19)$$

The corresponding radius of curvature of the wind path (of the isobar, if $i = 0$) will be

$$R_c = \frac{\delta p \cos i}{\rho\omega^2 \sin^2\varphi} \qquad (20)$$

From these equations we learn that for every anticyclone the condition of the steady flow of winds nearly parallel to the isobars can not be satisfied within the central regions of the high because the radius of curvature is too short and very high velocities are necessary.

Critical isobar.—The word *critical* has come to be applied to the limiting conditions in anticyclones under which "gradient" or "steady" winds become possible. Thus we have "critical isobar," "curvature," "velocity," and the like.

The *critical isobar* of a HIGH is significant in atmospheric motions in that, within the area inclosed by it, the winds blow outwardly at a relatively high angle across the inner isobars. Unless friction is too great, the speed of

[13] Mechanics of the Earth's Atmosphere, Abbe, C. Paper by Gold, E., Smith. Misl. Coll., No. 4, p. 113.

outflow will be accelerated by the gradient and attain a relatively high velocity. The flow then comes to be more and more deflected by the earth's influence until it reaches the isobar of critical curvature, where it comes into a state of steady motion at its maximum, or the *critical velocity*.

Because of these conditions we find that beginning with small gradients and gentle winds at the central portions of highs we may look for winds of the highest velocities far away from the center and along the *critical isobar*, whose diameter is generally considerable. Beyond the isobar, especially in the direction of an adjacent low pressure system, the curvature of the isobar and also the speed of the wind diminishes as the isobars merge into parallel straight lines. Passing onward from this region toward the center of a LOW the velocity decreases as the curvature of the isobars increase, but generally in nature the gradient in lows increases toward the center, and at times becomes very steep with high gradient wind velocities.

Comparing equations (12) and (19) we see the steady wind along the isobar of critical curvature is exactly twice as great as the steady wind for parallel straight isobars, and for the same pressure gradient and angle i.

While the steepest gradients and the highest winds occur with cyclonic conditions, nevertheless gradient winds of the anticyclone have much higher velocities than those of the cyclone, when the pressure gradient and curvature of isobars are the same in both cases. It can easily be shown that regardless of the latitude the velocity along an isobar of critical curvature of the anticyclone is $\frac{1}{\sqrt{2}-1}=2.414$ times the wind along an isobar of the same curvature and same pressure gradient in a cyclone.

In the foregoing the configuration of the anticyclonic system has been regarded as closely circular in outline. In nature, however, HIGHS repeatedly occur of gentle gradients and enormous extent, not only laterally, but especially extended longitudinally so as to constitute a veritable ridge of high pressure, overspreading an extended region. Such are frequently found over ocean areas. The isobaric lines of such a system lack curvature and are practically parallel straight lines in the direction along the axis of the HIGH, and the outflow therefrom, when the equilibrium stage has been attained, conforms closely to the motion shown in figure 3. The parallel straight lines are in fact the isobars of *critical curvature* for this condition and the *critical speed* in this case, equation (12), as we have seen, will be only half as great as the maximum possible speed for the same gradient in a HIGH with circular configuration; that is, with a radially divergent gradient.

These considerations explain why it is that weather maps frequently show great areas of high pressure in which the gradients are very gentle for a long distance from the center, beyond which critical distance the isobars, often nearly or quite straight lines, are crowded close together, marking a strong gradient and accompanied by high winds.

All this means simply that the air flowing initially *down the gradient* while gaining velocity finally attains its equilibrium state in steady motion nearly *parallel to the isobars*. The air flows across the isobars with difficulty and therefore the transfer of great masses of air from one place to another in order to satisfy a pressure deficit can not be easily and quickly effected. The principle of frictionless gradient winds means flow *perpendicular* to, not down the gradient. This thought leads to an interesting dynamic paradox, which may be stated thus:

Dynamic paradox.—If air is caused to flow from one place on a rotating globe to a more or less distant place (not near the equator) by a fixed pressure gradient steadily maintained, then paradoxically the greater the friction the more direct and easy the flow; the less the friction the more difficult the flow. If the friction is zero the flow to the distant place may be impossible, but the maximum velocity in the steady state will be finite, depending upon the gradient. (See discussion of the critical isobar in the HIGH.)

The permanent low pressure at the poles may be explained by noting that the outflow of air from this region as a whole is over the surface and in the lower strata, where friction, convection, etc., are greater than in the case of incoming air at higher levels. Hence, the region experiences a deficit of air until a pressure gradient is built up under which the inflow and outflow are just balanced. This principle is of course obvious enough but its wide application in connection with the existing permanent contrasts of pressure needs to be emphasized and recognized.

The following table presents instructive data giving gradient winds computed from equations just discussed for different latitudes:

TABLE 2.—*Gradient winds and curvature of isobars for critical conditions in different latitudes.*

[Isobars spaced 100 miles per $\frac{1}{10}$ inch. Density $\rho=.0010$ grams per cc. corresponds to free air at about 1 mile. Units are miles and miles per hour.[14]]

Latitude (degrees).	Critical velocity (High).	Radius of critical isobar (miles.)	Velocity same curvature in Low.	Velocity for straight isobars.
0	Infinite.	Infinite.	Infinite.	Infinite.
10	372	8,160	154	186
20	189	2,100	78.2	94.4
30	129	984	53.5	64.5
40	100	595	41.6	50.2
50	84.3	419	34.9	42.1
60	74.5	328	30.9	37.3
70	68.7	278	28.5	34.3
80	65.5	254	27.1	32.8
90	64.6	246	26.8	32.3

[14] A more complete table in metric and English units for various gradients has been published by the writer in Smithsonian Meteorological Tables, fourth edition, 1918, Tables 42 and 43.

V. EARTH'S SURFACE NEARLY GEOIDAL AND FRICTIONLESS.

Since our present object is to consider certain fundamental influences governing the great general motions of the atmosphere, we may regard the irregularities in the geoidal surface represented by the waves of the sea, for instance, or even the elevations of the islands and continents, however rough their topography or lofty their mountains, as inconsequential or of secondary influence. It is well known these topographic reliefs are insignificant as roughness on even a large-sized globe. On the other hand, it is also true that the whole atmosphere, although without definite outer boundary, is itself only a relatively thin layer. For example, the troposphere within which all the great convective actions occur embraces fully 75 per cent of the atmosphere yet has a thickness of only 7 or 8 miles. On a 12-inch globe a layer of the thickness of an ordinary blotting paper might represent this air, and the most lofty mountains almost pierce it at several points, and very extended mountain ranges project into it to heights of 2 or 3 miles. The actual superficial area covered by these real obstacles to the great motions of

the atmosphere, however, is but a small fraction of the whole surface of the globe, of which perhaps more than 90 per cent may, for present purposes, be regarded as oceans and smooth lowlands. Accordingly, in following the statements presented herein the reader is requested to keep vividly in mind the actual smoothness of the real geoidal surface of the earth and for the time being forget the irregularities which appear so exaggerated to our limited perceptions.

Careful reflection upon the foregoing seems to justify the statement that the geoidal form of the earth in the lower strata of the atmosphere, as a matter of fact, is realized with great perfection because the highly mobile air itself, rather than even water, constitutes the real surface. Portions of the air which remain at rest or nearly so because of terrestrial roughness themselves constitute the geoidal surfaces upon which the great motions of the air take place in a nearly frictionless manner. We are not required to think of motions over rough, irregular land areas, but simply of the free masses of moving air gliding easily and almost without friction over relatively thin layers of air held partly stationary by, and filling up, the actual roughness of the globe, in a manner which transforms, or literally lubricates, the actual solid figure into one of great smoothness over which the atmosphere moves in a practically frictionless manner. Obviously, however, turbulence and the convection of large masses of air offer very important obstructions to the movements in question and add to the smaller losses of energy due to the friction at the earth's surface.

These considerations lead indeed to the view that the actual motions of the atmosphere as we know them are in reality very nearly frictionless motions, and if every bit of frictional resistance were removed the motions under existing gradients would be much the same as at present. The energy now dissipated by friction would be saved and wind velocities would be slightly increased. Friction now permits and facilitates a very material interzonal flow, which would be suspended without friction, in which case, after a time, the present contrasts of temperature between the equator and the poles would be changed, causing changes in the pressure gradients. There is nothing, however, attendant upon the removal of all friction to support Ferrel's conception of the frictionless circumpolar cyclone.

Throughout all that precedes an effort has been made to acquaint the reader fully with a correct view and understanding of the forces, conditions, and influences causing and modifying the motions of the atmosphere and of bodies on a rotating globe. With such a correct understanding in mind the serious errors in the existing literature of the subject can be most clearly presented and discussed in connection with quotations such as follow:

VI. Citations From Authorities Showing Fallacies Herein Discussed.

There are two essentially different aspects of what is actually one fundamental fallacy leading to inconceivable wind velocities in atmospheric motions. (1) The equations offered by the mathematicians such as Ferrel, Helmholz, Oberbeck, and Bigelow, for example, all lead to very high velocities, which are difficult to explain. (2) Another class of writers, such as Davis, Hann, Angot, Milham, McAdie, Humphreys, and others, have endeavored to present the principles of atmospheric motions in popular language, but have introduced misinterpretations of their own so as to increase the confusion and misrepresentations. Since a fundamental difficulty still remains after clearing up the fallacy in the writings of the popular writers, it seems best to begin with the latter and then discuss the faults in the work of the mathematicians.

CITATIONS FROM POPULAR WRITERS.

Davis, W. M.—Mention has been made already that Davis first called attention to the friction fallacy when discussing Hadley's faulty theory concerning the change of velocity of winds with change of latitude.

Although on the right track in these matters, he was not consistent and later fell into the fallacy of superhurricane velocities growing out of vortical motions. After having applied the law of the *conservation of areas* to the vortical motions of water in a basin discharging through the center and likened the same to the vortical circulation of the atmosphere around the poles, Davis says (Elementary Meteorology, p. 110):

> 136. *Cause of low pressure around the poles.*—If the explanation of section 134 be now applied to the atmosphere, with the supposition that there is no loss of velocity by friction or other resistance, it is clear that an excessive velocity and a still more excessive centrifugal force would be developed in the circumpolar vortices. It should be noticed that the eastward motion of 1,000 miles an hour that the air has over the equator is increased as the overflow approcahes the pole; at latitude 60°, where the distance from the axis is half what it was at the equator, the eastward velocity has doubled; that is, it has become 2,000 miles an hour, or 1,500 miles faster eastward than the earth's surface at that latitude. Forty miles from the pole it would be 100,000 miles an hour; and so tremendous a velocity on so short a radius would suffice to hold the air away from a closer approach to the pole, if it could, indeed, approach so close as this; at any less distance there would be a vacuum.
>
> But the action of friction and other resistances can not be neglected. The presence of almost as great an atmospheric pressure in the polar regions as at the equator assures us that the imaginary case of no friction is far from the actual case. Although the resistances suffered by the upper air currents can not be great, they successfully prevent the realization of the enormous circumpolar velocities that would result in the case of no friction and no intermingling of currents.

The correctness of these statements may be questioned from two points of view.

(1) Friction and the dissipation of energy by convection, turbulence, eddy motions, viscosity, and all imaginable internal wastes are of the greatest importance and can not be neglected or overlooked in the full analysis of atmospheric motions. On the other hand, it is wrong to imply that slight atmospheric friction and other resistances suffice to prevent the attainment of the inconceivable eastward velocities of 1,500 miles per hour at latitude 60° and 100,000 miles per hour at 40 miles from the poles, which the computations by the law of equal areas give. It is very clear there is a serious error here. Friction plays an important part in the circulation of the atmosphere, but it does not play the part ascribed to it in the statement quoted.

(2) The law of equal areas applies to motions *under a central force*. Now in the case of the vortical whirl of water, or even of the cyclone, the hurricane, or the tornado, the only *active* central force is the convergent pressure gradient in the system. Gravity is *not* in such cases an active central force causing the gyrations except to the extent its action is expressed as a pressure gradient. Again, in the case of the circumpolar cyclone, practically all the authorities treat it just as if gravity were the active central force. This is entirely erroneous. The only circumpolar winds which are possible under any assumptions are simply the winds which would occur anywhere with the same pressure gradient, friction, and deflective force. We have already shown that the law of equal areas in connection with rotation about the

earth's axis can not act alone in any of these cases. It must act with the slope effect, simply as a passive influence which only guides the moving masses in a manner such that the law of momentum is satisfied at every point *with no change in velocity* unless such is required by actual changes in the gradient or the friction.

On a rotating earth the whole effect of rotation on atmospheric motions may be summed up in these words:

Rotation compels motions to become gyratory and the gyrations must always be in particular directions.

The deflective influence, f, varies in value from zero at the equator to a maximum value at the poles. This force represents the whole influence of the rotation. It is proportional to, but is powerless to produce or change velocity. On a stationary earth the motions of the atmosphere would not in general assume a gyratory character. Nevertheless, a gyratory motion could be set up just as it is easy to set up vortical outflow of liquid from a basin. In such cases the direction of gyration depends entirely upon the initiating cause and might be in either direction *ad libitum*, whereas rotation of a globe compels relative motions thereon to become gyratory and in a particular direction. But the motions must be set up first by some extraneous force, a pressure gradient as a rule. The advocates of polar hurricanes do not show the source of the inconceivable forces or gradients which alone could produce the excessive velocities. Air at full pressure flowing directly into a vacuum—a maximum conceivable gradient—could not attain the excessive velocities claimed for frictionless polar circulation. As is fully shown in Section IV by the equations for steady winds either with or without friction, acceleration of velocities ceases immediately when the pressure gradient and the deflective force are balanced. This absolutely fixes the possible velocity in any case and these are always moderate.

To move a body northward or in any direction on a frictionless stationary globe, we need only to push it northward or in any direction in which motion is desired. To move it northward on a globe rotating from west to east *we must push the body, not northward, but constantly westward*, when it will move westward to a slight extent but northward indefinitely unless started exactly at the equator. On a stationary globe steady motions take place in the line of action of the producing force. On a rotating globe, *perpendicular* to said line of action if frictionless, and nearly perpendicular if friction is slight. These truths have long been known, but writers have neglected their consistent application.

It will be shown later that anticyclonic gyrations are impossible on a stationary earth.

MILHAM.—The fallacy by this author is found in the following passage:[15]

146. The effect of this deviation to the right on the air masses which, due to convection, are moving from the equator toward the poles on the outside of the atmosphere must now be considered. Instead of moving directly from the equator poleward, the air masses will be deviated to the right in the Northern Hemisphere and become more and more a west air current encircling the pole in a great whirl. It is a principle of mechanics that whenever a rotating body is not acted upon by outside forces, the moment of momentum must remain a constant. The formula for the moment of momentum is ΣMVR, where M represents the mass of each particle of the rotating body, V the velocity of the particle, and R the radius, that is, the distance of the particle from the center of rotation. This product MVR must be summed up for all the particles of the rotating body, and thus ΣMVR represents the moment of momentum of the body. As this ring of whirling air about the pole approaches it, the mass remains constant, the radius is decreasing, and thus the velocity must steadily increase, and it has been computed that, if the velocities were not held down by friction, they would amount to hundreds of thousands of miles per hour. A whirl of air with these high velocities must cause centrifugal force, and this centrifugal force will hold air away from the pole, thus causing a diminution in the barometric pressure. The amount of land at the north pole is much greater than at the south pole. One would thus expect wind velocities and the diminution in pressure to be larger at the south pole than at the north pole.

As in the case of Davis, no distinction is made by Milham between the earth's deflective influence and the operation of the law of equal areas. This is the more remarkable because earlier, even on the same page, this author says: "The earth's rotation influences air moving in any direction and the velocity does not increase as the equator is approached." Why, then, should it increase as the pole is approached?

VON HELMHOLTZ[16] encountered the excessive velocities required by the law of equal areas and overlooked the correlative influence we herein designate the law of the geoidal slope

On page 82 we find:

For air that is resting quietly at the Equator in the zone of calms and is thence pushed up to the latitude of 10°, this expression gives tne acquired wind velocity 14.18 meters per second, and similarly for air pushed up to latitude 20°, 57.63 meters, and for 30°, 133.65 meters per second.

Since 20 meters per second is the velocity of a railroad express train, therefore these numbers show without further consideration that such gales do not exist over any broad zone of the earth. We therefore ought not to make the assumption that the air which has risen at the Equator reaches the earth's surface again unchecked in its motion even 20° farther northward.

The matter is not much better if we assume the atmospheric ring resting at some intermediate latitude. In that case it would give an east wind at the Equator, but a west wind at 30° latitude; but both velocities would far exceed the ordinary velocities of the observed winds.

Since now in fact observations do demonstrate a circulation of the air in the trade-wind zones, therefore the question recurs: By what means is the west-east velocity of this mass of air checked and altered? The resolution of this question is the object of the following remarks.

Helmholtz then sets up equations from which he determines the conditions of equilibrium between superincumbent strata with differing motions and temperature. In arriving at these equations he introduces terms representing the effects of the *centrifugal reactions* which we call the slope effect and then considers the turbulent and whirling intermixture which result from instability of strata. There seems to be no logical justification in classifying the slope effect with friction, turbulence, etc., and it seems quite uncertain what the effects of turbulence, etc., would be in his equations if he had treated the slope effect in a proper manner. Helmholtz's conclusions read:

From these considerations, I draw the conclusion that the principal obstacle to the circulation of our atmosphere, which prevents the development of far more violent winds than are actually experienced, is to be found not so much in the friction on the earth's surface as in the mixing of differently moving strata of air by means of whirls that originate in the unrolling of surfaces of discontinuity. In the interior of such whirls the strata of air, originally separate, are wound in continually more numerous, and therefore also thinner layers spirally about each other, and therefore by means of the enormously extended surfaces of contact there thus becomes possible a more rapid interchange of temperature and equalization of their movement by friction.

HUMPHREYS, W. J.—Statements claiming that atmospheric frictions, turbulence, etc., prevent the excessive velocities called for by the law of equal areas appear anew in the publication entitled "Physics of the Air," Journal of the Franklin Institute, November, 1917, page 660 (Book Form, p. 131), as follows:

Hence the velocity of the transferred air [from lat. 30° to lat. 60°], in question with reference to the surface is $v'-s$=1,036 miles per hour=436 meters per second.

[15] Milham: Meteorology, par. 146, p. 161, edition 1912.

[16] Mechanics of the Earth's Atmosphere. Translations by Cleveland Abbe. Smithsonian Miscl. Col., 843, 1891, V. On atmospheric motions.

As a matter of fact, no such enormous velocities of the wind as the principle of the conservation of areas would lead one to expect in the higher latitudes are ever found, either at the surface or at other levels. This, however, does not argue against the applicability of the principle itself, but only shows that in the case of atmospheric circulation there are very effective damping or retarding influences in operation.

The resistance due to the viscosity of the atmosphere is one of these retarding influences, but its effect probably is very small. A larger effect doubtless comes from surface turbulence induced by trees, hills, and other irregularities. A still greater velocity control, probably so great that all others are nearly negligible in comparison, except near the surface, is vertical convection. This phenomenon leads to extensive interchanges between lower and upper layers of the atmosphere, thus indirectly increasing the effect of surface friction probably several fold and tending to bring all the lower, vigorously convective, portion of the atmosphere to a common velocity. Because of these several means of control the actual wind velocity everywhere is different and at high latitudes much less than it otherwise would be.

Not only is the velocity of the wind changed through change of latitude, but also the rate at which its direction with reference to the surface of the earth varies or tends to vary.

It seems obvious, on sober reflection, that the slight frictional resistances itemized in the foregoing could not possibly reduce the inconceivable velocity of 1,036 miles per hour to even hurricane winds, much less hold it down to the average gentle winds of our everyday experience.

Like others, this author disregards the operation of the slope effect. In fact, in the publication cited all discussion of the slope effect, the *dual* nature of the deflective influence of the earth's rotation and the interrelation between these concepts and the law of equal areas is entirely omitted. A method is employed for demonstrating the deflective influence which is of doubtful value because it conceals from the pupil the very information it is most important for him to know and fully understand, namely, that, as Ferrel so clearly showed at the beginning, the passive deflective influence is the resultant of two wholly separate and independent inertia reactions. These are the momentum effect in the one case, and a lateral component of the so-called centrifugal effect or the slope effect in the other case.

Attention is called also to the the further misrepresentations in the closing paragraph of the quotation from Physics of the Air. The opening words imply the velocities of winds change with change of latitudes, whereas it has been shown repeatedly that change of latitude does not in itself lead to changes in the velocity of winds and freely moving bodies.

Furthermore, the rate of change of wind direction with reference to the surface of the earth, due to the deflecting influence of the earth's rotation, is not correctly expounded in the text following the quotation. The numerical values of angular changes per hour given in the table on page 665 (136 Book edition) are not changes in the direction of the wind, as the context clearly implies, but are simply the angular turning of the ground, whereas the changing in the direction of motion of winds and freely moving bodies is double the amounts given, as already stated in Section III of this article.

MARVIN, C. F.—The writer acknowledges having been formerly misguided by the concurrent writings of many high authorities on these questions and himself subscribed to the friction fallacy. (See Weather Forecasting in the United States, p. 17.)

These citations, and several others of like import which might be added, are erroneous, because the writers have disregarded the slope effect and have ascribed to friction the part it plays in controlling the operation of the law of equal areas.

The soundness of any of the statements of excessive velocities quoted can not be justified on the ground that they are correct for the conditions upon which they rest. This defense is unacceptable. The statements quoted were written for the instruction of uninformed readers upon a very obscure question of dynamics, and the statements should be correct on their face. The reader can not be expected to supply missing information. As a rule, the absence of friction is the only condition specified and the inference is permitted and generally entertained that bodies once set moving in latitude without friction would continue to change their latitude indefinitely. In all the statements dealing with excessive velocities under the law of equal areas the reader is left ignorant of the peculiar conditions under which the statements might be correct. For example, indefinite changes of latitude with excessive velocities in longitude would occur on the assumption, which however is nowhere stated, is not tenable and is not even generally recognized as a condition—namely, that the pull of gravity *on the moving body* is exactly perpendicular to the smooth geoid. Such a condition is wholly impossible in nature.

Again, waiving the condition just stated, reflection will show that the excessive velocities claimed in any case, as for example, the velocity of 1,036 miles per hour, might be attained by a body reaching a latitude of 60° *provided it was started northward at 30° with a velocity of 1,036 miles per hour.*

We may feel confident that these limiting conditions would have been fully mentioned if clearly perceived by any of the writers, since to omit such important factors consciously would have been inexcusable. On the other hand the complete absence of any allusions to such limitations justifies the claim that the statements are erroneous as they stand. In any case, moreover, it is the operation of the neglected slope effect, not friction, that prevents the excessive velocities.

What we consider the fundamental fault still remains, and for this chiefly the mathematicians are responsible. I think we may fairly say that the original error starts with Ferrel and has been perpetuated for the last 60 years in all standard writings.

Ferrel's writings are very clear on the subject of the deflective influence, and its two components, both of which were properly included by appropriate terms in his general equations.

Even to the present day it is difficult to overestimate the remarkable originality of Ferrel's work especially when we consider how little was known of general meteorology at the time, 1858, he produced, in almost its finished state, his mathematical theory of the circulation of the atmosphere.

In spite of this, however, he appears to have fallen into important errors arising from a disregard of the control exercised by the slope effect which led to serious misconceptions of inconceivable velocities to which his final equations lead when friction is assumed zero or negligible.

Citations from mathematical papers.

It is believed the crucial question at issue may be stated to be—

What is the nature of the *frictionless* circulation of the air of a polar hemisphere assumed to be warm at the equator and cold at the poles?

For such studies the two polar hemispheres of the earth may be regarded as entirely independent units, completely separated by the plane of the equator extended, across which all reactions are neutral.

Ferrel approached the solution of this question by first assuming the air at rest and no temperature gradient, the

air being given an initial impulse in the plane of the meridians. The result gave him his circumpolar cyclone with polar winds of inconceivable velocities whereby the air from its own motion would entirely recede from the poles, be greatly depressed at the equator and form a bulge of high pressure at lat. 35° 16′[17].

On page 195 of Recent Advances, he says:

> Hence in this case of no friction between the atmosphere and the earth's surface any stratum of equal pressure, however rare it may be and however high it may be in the equatorial and middle latitudes, must be brought down to the earth's surface near the poles.

This concept necessarily entails a vacuous region of material extent "near the poles," and is so shown in figure 6. This condition of pressure distribution involves motion, and of this Ferrel says on the next page:

> In the preceding results the motions are due to an initial impulse giving the initial velocities u_0, v_0 and x_0 and not to any constant temperature disturbance, since α, which is the only quantity depending upon temperature, has been treated as a constant.

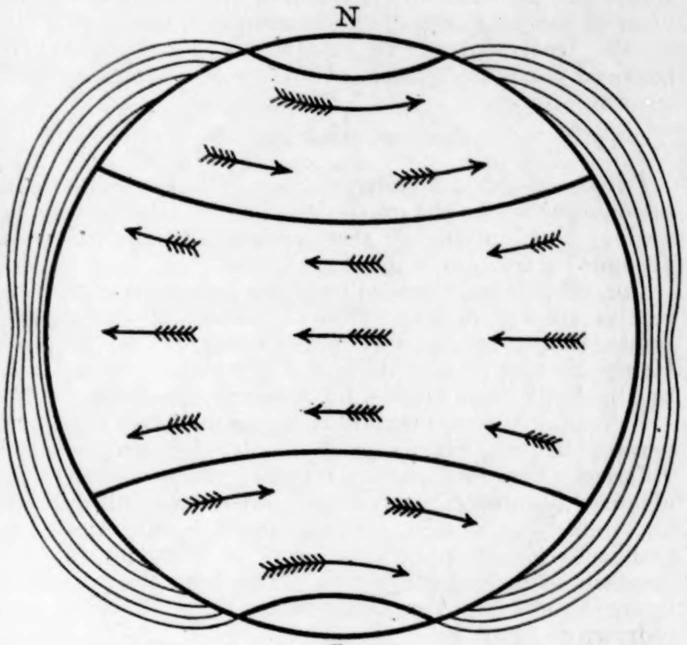

FIG. 6.—Reproduced from Ferrel, showing his frictionless circumpolar cyclone.

This concept has been practically universally accepted by meteorologists and taught up to the present time, subject, of course, to the assumptions upon which it is based.

The superhurricane winds at different latitudes required by this theory have been given already in the last column of Table 1 and are repeated in Table 2 below.

These conclusions of Ferrel very largely underlie all his subsequent theoretical deductions in which he endeavors to define the general circulation with temperature gradients and friction properly included. To the last he seems to have been able to satisfy his own mind at least that friction would suffice to check the incredible velocities demanded by this theory at both the equator and the poles.

Sober contemplation of such a circumpolar hurricane even granting frictionless motion simply compels the conclusion that it is obviously erroneous, unreasonable, and impossible. If such is the case can we still believe his more complete solution of the complex problem with temperature gradients and friction included is nevertheless valid? Probably not.

As in the case of the popular writers the soundness of the conclusions reached by the mathematicians can not be justified on the ground that they satisfy assumptions. Let us examine this question briefly.

While for directness of presentation we shall confine our analysis to Ferrel's writings as the leader in these matters, nevertheless, his mistakes must be shared by all those who have followed in his footsteps.

He says of his frictionless circumpolar cyclone (see citation above): "In the preceding results the motions are due to an initial impulse giving the initial velocities u_0, v_0, and x_0". Elsewhere he makes it clear he assumes the initial state of the air before receiving the impulse to be that of "rest relative to the earth's surface." The assumption relative to the initial impulse is vague and indefinite. It is difficult to imagine any kind of an initial impulse that would satisfy the idea in Ferrel's mind, or even one that would produce results such as he claims would follow. We may assume each particle receives an impulse peculiar to itself, but clearly such a condition involves great complexity, and it is certain Ferrel never would have omitted to cover such an important point if such a thought were entertained by him. On the contrary, we may be sure Ferrel thought that, in the absence of friction, particles set moving northward would continue moving northward indefinitely. For example, imagine that a great ring of free upper equatorial air is given a powerful impulse projecting all particles exactly poleward. Helmholtz entertained a view somewhat like this. Would such an impulse induce a circumpolar cyclone like Ferrel's? Not at all. Every particle disturbed by the impulse, if close to the equator, would tend to execute motions such as Whipple has demonstrated, and if more distant from the equator the motions set up would tend to circular paths, according to the explanation of figure 2. If we wholly disregard the action of the slope effect, as we feel confident Ferrel and all those who have accepted his view unwittingly did, it seems quite certain that the assumed atmospheric ring once started northward would continue to cross lines of latitude indefinitely, and at the same time take on the high easterly velocities given in column 4 of Table 1. Assuming, further, that the northward motion of the ring is communicated without loss of energy, but reduction in northward velocity, to all the other particles of the polar hemisphere, it is easy to concede on an untenable basis, which neglects the slope effect, that a frictionless circulation like Ferrel's, with inappreciable motion in latitude but excessive eastward drift, especially in high latitudes, might be induced.

On this basis, however, Ferrel's circumpolar cyclone is erroneous because based upon an impossible condition which he and his followers have unconsciously adopted.

The writer is further inclined to believe that Ferrel's theoretical high pressure belt at latitude 35° 16′ is also fallacious and in the nature of a mathematical fiction, or the result of unnecessary or inapplicable assumptions.

However, this matter can not be lightly dismissed because Ferrel's entirely original work is strongly supported by like conclusions reached later by other mathematicians, such as Helmholtz, as already cited, Oberbeck, Bigelow, and others. This is made clear most easily by citations from Bigelow[18], who made a detailed com-

[17] Ferrel: Professional Papers, Signal Service, No. 8, p. 21, fig. 4; Recent Advances, Annual Report, C. S. O., 1885, pt. 2, p. 195, fig. 3; Popular Treatise on Winds, p. 118, sec. 81; also pp. 48, 67-69.

[18] Report on international cloud observations. Annual Report Chief of Weather Bureau, 1898-99, pt. 2, p. 588.

parative study of the mathematical work of Ferrel, Sprung, Guldberg, and Mohn, Oberbeck and Pockles. Bigelow was not fully convinced of the soundness of the conclusions reached by the mathematicians and considered the friction concept a perplexity. Taking up Oberbeck's work, which carried forward and improved upon the work of Guldberg and Mohn, Bigelow writes (p. 606):

Oberbeck's solution taken in connection with Ferrel's, constitutes the theory commonly taught by meteorologists. That it is partially correct, even admitting the limitations with which the solution was executed, is apparent, as it is verified by the general features of the circulation of the atmosphere. But there are, nevertheless, some important modifications which must be incorporated into this theory before it reaches a satisfactory statement. The first concerns the *return current* from the tropics toward the poles; the second the process of checking the excessive esatward *drift* in the higher latitudes; and the third the evaluation ot the friction coefficient.

Bigelow by no means succeeds in clearing away the perplexity of "the process of checking the excessive east-

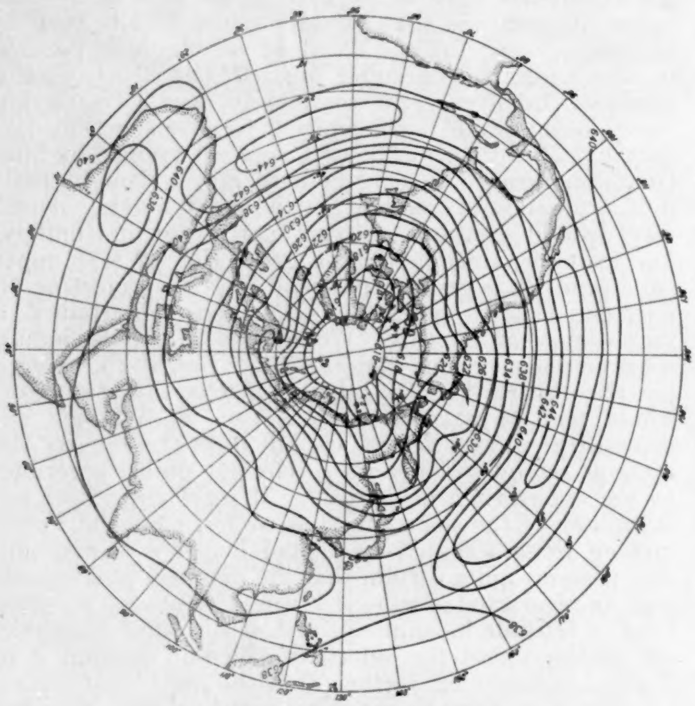

FIG. 7.—Isobars at 1,500 meters, January.

ward drift," although he devotes several pages of his cloud report to its discussion. He says (p. 607):

If the source of retardation conceived by Prof. Ferrel is not correct, is it possible to give another statement agreeing with the facts, and yet efficient in its operation to produce the required results? For it must be admitted that a very effective agency is in operation to act as a brake or check of sufficient power to reduce the theoretical eastward drift from the velocities of Table 122 [see Table 3] to those of Table 124. (Cloud report, p. 606.)

On page 614 he adds:

Fuller descriptions of these equations may be found in Prof. Ferrel's works. The chief impression regarding them is that they are detached in the discussion, one feature at a time alone being considered. Oberbeck's analysis has the advantage of much greater coherence and completeness, and in that respect is more satisfactory. At the same time it must be admitted that both systems give about the same picture of the general cyclone, if the assumptions introduced into the discussion are taken to be correct. Our criticism shows that these must be modified before the observed motions of the atmosphere are completely accounted for. It still remains, however, a very hard problem to solve practically.

In his later work, Atmospheric Circulation and Radiation, it seems Bigelow is still baffled and perplexed by the problem of friction and excessive velocities. On page 179, about friction [19] he writes:

This is a subject that has not been satisfactorily cleared up and it will require much careful research.

After deriving again essentially Ferrel's equations, Bigelow says (p. 191):

Ferrel discusses these equations and gives some approximately correct views regarding the general circulation. Oberbeck's treatment embraces the three equations of motion and the solution approaches more closely to the flow of currents actually observed. The complete intergration of the system is, however, more complex than has been admitted and the problem awaits a better treatment. The actual velocities and direction of motion, together with the temperature, must be so handled as to embrace the general and local circulation in a single comprehensive system.

Such are the comments of a man after spending more than 15 years arduous study to the subject of theoretical meteorology.

It seems quite certain, then, we are dealing here with a very fundamental and important difficulty, if not a real error in the dynamics of the atmosphere, due apparently to the treatment of, or limitations which have been imposed upon, the general equations of motions by their several authors.

Rational polar cyclone.

Let us see if it is not possible to construct a more rational answer to the crucial question of the circumpolar cyclone by applying to the problem the equations for cyclonic frictionless or gradient winds.

For this purpose we will confine ourselves closely to results drawn directly from observations. Figure 7 shows the mean January pressure over the Northern Hemisphere at an elevation of 1,500 meters, as redrawn by Bigelow [20] from studies by Tiesserenc de Bort.

Following the mathematicians' assumptions that temperature is constant along all parallels but progressively different from latitude to latitude, there is only one idealized barometric map of such a polar condition possible, namely, a system of concentric circular isotherms and isobars each parallel to lines of latitude. Such a diagram, in no material sense, differs from the cyclone of figure 5, and for simplicity figure 7 is idealized and redrawn in figure 8.

The outermost isobars are shown as fragments of straight lines and as arcs of very great radii because as wind tracks the Equator is a straight line and the adjacent parallels have very great radii of curvature. This helps the mind to see in the diagram the effects resulting from the curvature of the earth from the Equator to the pole.

There is very little *a priori* basis on which we can say definitely what the actual pressures should be from latitude to latitude in this hypothetical case, but the observations indicate a tendency to the existence in the lower strata of a permanent high-pressure belt along tropical latitudes accompanied by low pressures at the Equator and the poles. This is very clearly apparent in de Bort's map. In an arbitrary manner, therefore, let the belt of maximum pressure be represented by the very heavy isobar in figure 8 at latitude about 30°. Within this isobar the circulation must necessarily be cyclonic because the gradient decreases toward the center. Between this isobar and the Equator the circu-

[19] A contribution to this question of far-reaching importance has been made recently by G. I. Taylor on eddy motions in the atmosphere. See Phil. Trans., vol. 215, 1915, pp. 1-26. Proc. Roy. Soc., Ser. A, vol. 92, pp. 196-199.
For abstract and review of above by Eric R. Miller, see MONTHLY WEATHER REVIEW, vol. 47, October, 1919, p. 703. C. F. M.

[20] Bigelow: International Cloud Report, loc. cit. Tiesserenc de Bort: Report on General Circulation of the Atmosphere, London, 1893.

lation is obviously anticyclonic. For frictionless motions the velocities are given by equations (15*a*) and (17*a*), but if we disregard, as is fully justified, a region near the poles the actual *curvature* of the remaining isobars can everywhere be entirely neglected with scarcely appreciable error. Consequently equation (13) for straight isobars gives the desired relation between the wind velocities, latitude, and pressure gradients. Now we can not know exactly what the final permanent pressure and temperature gradients would be after the atmosphere had attained a stable state of perfectly frictionless motion. We do know, however, that the friction in the free air, at least, is very small on the whole and we are compelled to conclude that until time permits temperature contrasts to change the pressure gradients as shown in figure 7 very nearly at least represent gradients for frictionless flow. With friction the winds must necessarily blow

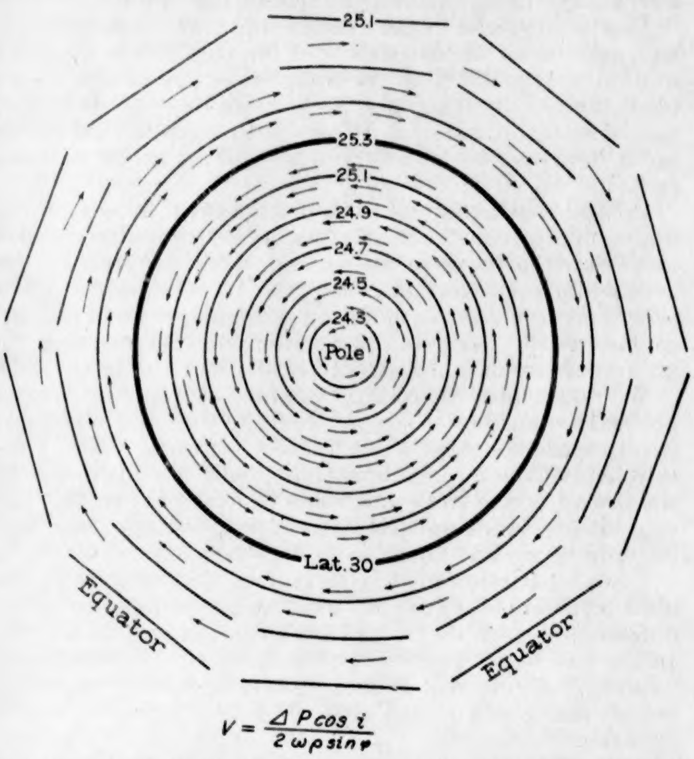

FIG. 8.—Figure 7 idealized by assuming pressure constant along parallels of latitude and belt of high pressure uniformly at latitude about 30°. The pressure and gradients are as nearly as practicable the same as in figure 7.

across the isobars at a certain angle i, and the velocity will then be given by equation (12), viz:

$$V=\frac{\delta p \cos i}{2\rho\omega \sin \phi} \tag{12}$$

Now the angle i is everywhere quite small except close to the surface of the earth and near the Equator. Even if i has a value of 10° or 15° the value of cosine i will differ but 1 or 2 per cent from unity, hence perfectly frictionless winds under these conditions can not exceed the velocities *with* friction by more than a very few per cent. These considerations which set forth the difference between winds with and without friction are too generally overlooked and disregarded. The important point is that *steady winds flow across the isobars at angles as great as 10° to 15° with only a small falling off in velocity below the gradient velocity.*

Assuming figure 8 to represent literally frictionless conditions we can easily calculate the gradient velocities for the different latitudes from equation (13). For this purpose we must recognize that over the belt of maximum pressure the gradient and hence the velocity is zero. Toward the Equator it is feeble, as shown by Teisserenc de Bort's chart, viz., about 4 mm. in 30°, which is a gradient of only one-tenth inch per 1,400 miles. Within the heavy isobar the gradients are steeper and nearly uniform except that data are mostly wanting within 10° or 15° of the pole. We know to a certainty, however, that no unusual gradients obtain even here. The data we have show we are fully justified in spacing the polar isobars at about one-tenth inch per 5°, or 350 miles. Taking $\rho=.00100$, equation (13), also Smithsonian Meteorological Tables, 4th edition, Table No. 42, gives the approximate gradient winds for this *rational circumpolar cyclone* as shown in the following Table 3, in which is also included the velocities for the circumpolar frictionless hurricane arrived at by the mathematicians.

TABLE 3.—*Contrasting the frictionless circumpolar winds in the lower strata derived by the mathematicians and the gradient winds in a rational circumpolar cyclone.*

[Velocities in miles per hour. +eastward, −westward flow.]

Latitude	Mathematical cyclone velocity.	Rational cyclone velocity.	Assumed gradient: $\frac{1}{10}$ inch per—
° ′			*Miles.*
0 00	− 346	−00	1,500
10 00	− 320	−12	1,500
20 00	− 239	− 6	1,500
30 00	− 100	− 0	∞
35 15	0	+ 6	1,000
40 00	+ 108	+16	350
50 00	+ 410	+13	350
60 00	+ 865	+12	350
70 00	+1,669	+11	350
80 00	+3,807	+10	350
90 00	+ ∞	?	?

Obviously, the velocities by the two methods of solution are irreconcilable to a striking extent, although both in fact are derived from exactly the same fundamental dynamic principles. The analytic treatment in one case leads to unknown and inconceivable winds at the poles and excessive velocities at the equator, while the results reached by the other treatment are rational throughout.

The writer is convinced the gradient winds are correctly derived, whereas the mathematicians in the final solution have circumscribed and limited their general equations in a manner which has literally precluded the operation of the law of the geoidal slope and has left the law of equal areas free to require the inconceivable velocities to which their equations lead. This is obviously a difficulty only in the *solution*, not in the original *statement* of the equations. The one solution which seemingly all mathematicians have been satisfied to follow is fallacious because the latitude effect and the slope effect are not simultaneously satisfied, as must be the case.

The writer particularly requests that the reader will not suppose that the so-called *rational polar cyclone* is offered as a representation of what exists in nature. Nothing of the kind is intended. It is a mere fragment and is offered to show a *method of solution* of certain equations of motion in such a way as to satisfy the requirements of terrestrial mechanics. In this method the *gradient* is recognized and treated as the independent variable. Moreover, the dependent deflective influences due to relative velocity and the earth's rotation are simultaneously, not separately and independently, satis-

fied as in the usual mathematical treatment. To make the application of this method to the entire polar hemisphere, isobaric maps must be available for all altitudes from the surface to the limits of the atmosphere. More attention must be given to the motions *in the vertical*. The flow of air in any given layer or stratum will be determined by the pressure distribution *in that stratum*, and this can not be correctly inferred in many cases from the surface pressures, as meteorologists are too prone to do.

There is no inherent necessity whatever that the ideal circumpolar cyclone shall be centered at the pole. The center might just as well be over Alaska or Iceland or elsewhere. There may be even two or more centers. The circulation is produced *by the gradient*, which in turn results from temperature contrasts. The rotation of the earth simply requires a gyratory circulation, whereas the mathematicians have fairly made the *rotation* produce the circulation. This seems to result from a failure to discriminate adequately between *real active forces*, like a pressure gradient, and those other things, like the momentum effect, the slope effect, the earth's deflective influence, and the so-called centrifugal force, which are all passive inertia reactions and which unfortunately are treated too often as if they were real forces capable in and of themselves of *causing* definite motions. All these quantities, including friction, are wholly *dependent* terms in the physics of these questions. It will be noticed that the local and the circumpolar cyclone are identical mathematical concepts except for the following unimportant particulars.

The polar cyclone is large, with many isobars of enormous radii of curvature, is cold at the center and warm at the outer limits. The value of f, the deflective influence of the earth's rotation, varies all the way from zero at the equator to a maximum finite value at the poles. Finally, the polar cyclone is stationary.

The local cyclone is small, with isobars of short radii. The contrasts of temperature in it are uncertain and probably of incidental significance. The value of f changes but little throughout its extent. Finally, in general the system often has a definite motion of translation.

Nonrotating earth.—It will also be noticed that a correct mathematical theory of the cyclone on a rotating earth can be transferred bodily to the atmosphere of a stationary earth, and vice versa, assuming of course all other conditions remain unchanged. For the stationary earth, $f=0$, and some initial impulse is then required to start a gyration, which may be clockwise or counterclockwise *ad libitum*. In other words, the only effect of the earth's rotation on the mathematical theory of cyclones is (*a*) to introduce into the equations of motion the passive reaction f, of variable magnitude, depending upon latitude and velocity; (*b*) to compel gyration in all cases and always in a particular direction. These considerations prompt the suggestion to the mathematicians that the theory of cyclones be first built up for conditions of a stationary earth.

Reference to the diagram of forces, figure 5, for the anticyclone shows that if $f=0$ (stationary earth) there can be no force to give curvature to the wind tracks. *Hence what we now know as anticyclonic circulation could have no existence on a stationary earth.* All gyratory circulation must necessarily be cyclonic on a stationary earth, just as is found to be the case on the rotating earth near the Equator, where f is small or zero. However, on a stationary earth gyration must be set up by some extraneous force and may be in either direction.

There is another very important consideration I wish to urge.

Ferrel's generalized frictionless polar cyclone with no change of temperature or pressure in longitude, as likewise the idealized rational cyclone of figure 8, even any system of mean monthly isobars, as Tiesserenc de Bort's chart for January, should not be supposed to REPRESENT a polar circulation and pressure. The most that can be said of these generalized, averaged, or ideal systems is that they lead to a circulation and pressure distribution that are *equivalent* to the actual circulation. By actual I mean the circulation hour by hour, day by day, with all its great changes.

We may say that a triangle is *equivalent* to a circle if the areas are equal, but the one form can not represent the other. Neither does the generalized circulation *represent* what actually occurs in nature, although the final effects may be equivalent the one to the other.

In the idealized polar cyclone the isobars necessarily run parallel to the latitude and for frictionless gradient motion interpolar flow is impossible. Actually, however, the isobars from hour to hour and day to day cross the lines of latitude *ad libitum* with unrestricted interpolar flow possible at any and all times with or without friction.

Critical mathematical examination may show it to be impossible to construct an *idealized* circumpolar circulation which is equivalent to and fairly represents the actual daily circulation *and at the same time will fully satisfy the requirements of the law of equal areas and friction as they exist.* Such an idealized circulation can not be an actual circulation but only equivalent thereto.

We must not, therefore, assume, although it seems perfectly plausible to do so, that the pressure and temperature are constant along lines of latitude. This limitation involves an incompatability with the operation of the law of equal areas and leads to irrational results because it precludes isobaric lines from crossing parallels of latitude as we find them to do freely in nature.

If we let friction modify as it does the motions in the ideal cyclone of figure 8, what are the results? The difference is very slight. Let the friction angle i be 10°. In the free air it is probably less. By equation (12) the "steady" winds will fall only 1½ per cent in velocity below the gradient velocity of Table 3, and by the equation

$$\text{Motion along meridians} = V \sin i$$

we find the whole mass of air could move poleward at a velocity of about 17 per cent of the actual linear motion. This method of analysis, although obviously incomplete in many details, nevertheless leads to a perfectly moderate and rational cyclonic circulation either *with or without* friction.

Returning to a consideration of Table 3, the remarkable feature of the gradient winds therein is the very moderate velocities everywhere except near the Equator, where alone the theoretical winds are seemingly inconsistent with observation. Any of these values will be halved or doubled by doubling or halving the spacing of the isobars. Clearly, therefore, these gradient winds harmonize in a wholly satisfactory manner with observations, because even in the equatorial belt of calms the discrepancy is not real, but only apparent, for two reasons: (1) The gradients here in general are very feeble, less than one-tenth inch per 1,000 miles. (2) The circulation in many cases, *probably never* attains any approach to the case of gradient winds, especially at the surface. Feeble gradients, slight temperature contracts,

and weak deflective forces over a wide equatorial belt constitute conditions under which the air flows easily and directly from place to place at small velocities, which even very slight friction suffices to hold down far below the theoretical velocities representing frictionless motions under strictly gradient conditions.

It is very certain from the foregoing that the equations of the mathematicians for frictionless motion on a rotating globe must yield wind velocities comparable with those in Table 3 for gradient winds before one can be satisfied that a fairly satisfactory analytical solution of the general circulation of the globe is attained. Possibly the problem may be approached anew by recognizing that the great systems of permanent isobaric lines for the surface and free air really mark out the great winding lanes and highways nearly parallel to which the perpetual flow and counterflow of the air must take place between the equator and the poles.

It is impossible in this already overlong article to cover fully all phases of the issues raised or point out the numerous fallacies in textbooks consequent upon the general disregard of the action of the slope effect in atmospheric motions.

Hann and Hildebrandsson,[21] with others, have questioned the accuracy of Ferrel's theories of the general circulation by showing material inconsistencies between theory and observations. The writer does not know, however, that any serious question has been raised heretofore regarding the soundness of the mathematical analysis itself or the correctness of the application of the physical and dynamic principles involved. If the representations in this paper are sustained, the cause for discrepancies between theory and observations is identified.

A very convincing proof that the claim of excessive polar winds for frictionless conditions is erroneous may be found in the sober reflection that atmospheric friction, especially in the free air, is very small at the most and that many observations tell us polar winds and pressure gradients do not differ materially from winds and gradients elsewhere.

Pilot balloon observations.—The foregoing studies give a new significance and importance to the observations in the free air by means of pilot balloons, which in a comparatively inexpensive way tell us at least during clear weather the velocity and direction of the wind in the various strata. By extending the observations to the highest altitudes attainable and occupying stations in equatorial and polar regions, about which little definite is now known, information of great value upon the motions and pressure gradients in the free air can be secured.

Obviously much work is now necessary to reconstruct a new mathematical analysis of atmospheric motions free from the faults it is believed have been brought to light in this paper.

SUMMARY AND CONCLUSIONS.

The writer is conscious the foregoing representations are more or less involved and indirect because it has been necessary, first, to establish and call attention to certain deep-seated and widespread errors in meteorological literature and at the same time to clearly explain the operation of certain obscure dynamic actions which, while heretofore known, nevertheless have been neglected or not consistently applied in mathematical writings as they should have been. It, therefore, appears appropriate to conclude this paper with a number of categorical statements giving important principles which the motions of the atmosphere must satisfy.

I. The rotation of the earth or any globe on its axis gives rise to two inseparable, independent, dynamic reactions upon matter in free relative motion. (1) The conservation of angular momentum requires that changes of latitude be accompanied by changes of velocity in longitude. (2) A component of centrifugal reaction introduces forces in the plane of the meridians whenever there are any relative motions in longitude. (3) These two reactions must always be simultaneously satisfied. Their resultant is the so-called deflective influence of the earth's rotation, which is entirely passive in its effects.

Free frictionless motions.—A body set into free frictionless motion over a smooth rotating globe by some initial force which then ceases to act will continue in motion forever, never changing its velocity, but constantly changing the direction of the motion unless it is exactly along the equator.

II. *Sustained force and ultimate velocity.*—If the force is not of a periodic character but sustained indefinitely a *constant velocity of finite value* will be attained. Enormous or infinite velocities result only from enormous or infinite forces. An initial impulse imposed upon an atmosphere at rest leads in general to initial surgings and oscillations with subsidence into eddy motions and vortical secondary developments which ultimately must embrace the whole atmosphere if not dissipated by friction. A permanent circumpolar cyclone, even if assumed to be limited to one hemisphere, can not be induced by an *elementary* initial impulse, as Ferrel assumed. The initial cause must be adequate to create the cyclone which would then continue forever if not subsequently dissipated by friction.

III. *Deflective influence passive.*—Neither the deflective influence not its components can act alone and *produce* motions. Their parts are to control and modify the directions *only*, of motions whenever set up or maintained by extraneous forces.

IV. *Active forces and velocities attainable.*—Since the deflective influences are powerless to produce or change velocities, therefore the velocities which can be attained will depend entirely upon the extraneous forces and the resistances encountered by the motions thus set up.

V. *Deflective influences always satisfied.*—Whatever entirely free motions may be set up, the demands of the slope effect and the latitude effect will always be automatically satisfied according to the momentary velocity in longitude and the changes in latitude. If the motions are constrained, as by tracks, banks or like fixed obstacles, the demands of the deflective influences will be expressed as lateral pressures of some kind.

VI. *Friction always present to produce rest.*—In all atmospheric motions, convections, turbulence, frictions and internal wastes of energy of many kinds are always present. These will soon dissipate and stop any free motions not continually maintained by active forces.

VII. *Pressure gradients active forces.*—The immediate forces which produce the general motions of the atmosphere arise by virtue of, and are measured by, pressure gradients.

VIII. *Gravity, pressure gradients, temperature contrasts.*—Pressure gradients in air and other fluids are *gravity reactions* and in the grand case of the whole atmosphere the permanent gradients depend chiefly upon the great *contrasts of temperature* which arise and are perpetually maintained by the unequal heating of the earth's surface by the sun which, in conjunction with the continuous losses of heat by terrestrial radiation,

[21] Hann: MONTHLY WEATHER REVIEW, 1914, vol. 42, p. 612. Hildebrandsson: MONTHLY WEATHER REVIEW, 1919, vol. 47, p. 374.

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cause the perpetual warmth of the tropics and the extreme cold of the polar regions.

IX. *Steady motions under balanced forces.*—Whatever free motions may be continuously maintained against resistances by active forces, a state of steady motion under balanced forces must soon be established. If the active forces and the opposing resistances are constant the velocities in the steady state will always be constant regardless of the direction of motion. Changes of both velocity and direction must always accompany changes in amount or character of the active forces or resistances, except in the improbable case in which simultaneous changes in both force and friction just offset each other.

X. *Flow of air tends to minimum, or state of rest.*—The flow of masses of the air from places of higher to places of lower pressure obviously at once tends to reduce or dissipate the pressure gradient to fill up the low, after which friction stops the motion. Such flow also tends to reduce or remove temperature contrasts and any like causes which tend to create and maintain gradients. In other words, *all motions of the atmosphere due to temperature contrasts and pressure gradients tend automatically to the minimum of motions, or to a state of rest.* First, because even without friction the flow and intermixture must equalize temperatures and dissipate gradients or reduce these to a minimum. Second, the surging and oscillating motions of great complexity which conceivably might be set up and continue forever without friction, must by it be readily damped out or reduced to a steady state of the minimum motion.

XI. The motions of the air must satisfy the equations of continuity which require that the inflow and outflow for a given region shall be equal on the average.

XII. Hadley and others since assume, without adequake basis of proof, however, that the algebraic sum of all the frictional affects between the air and the earth for the entire surface of the globe is zero, because otherwise a change in the period of rotation of the earth on its axis should be in evidence.

The foregoing is believed to clearly state principles of great fundamental importance in dynamic meteorology. The whole difficult problem of the mechanics and thermodynamics of the atmosphere is comprehended in the steady winds and the changing motions, for which simply the conditions are stated in paragraphs IX and X.

The literature of mathematical meteorology in so far as it relates to atmospheric circulation is an effort to satisfy in mathematical terms principles IX and X.

THE GREAT CYCLONE OF MID-FEBRUARY, 1919.

By C. LeRoy Meisinger.

[Weather Bureau, Washington, D. C., Oct. 23, 1920.]

SYNOPSIS.

Between the 10th and 16th of February, 1919, the United States witnessed the passage of a cyclonic storm of more than usual intensity, with almost circular isobars, with a diameter sufficient to overreach the northern and southern borders of the country, and with a persistence which enabled it to retain its identity from the time it appeared in the western United States until it disappeared off Newfoundland. A study of this storm, based upon the upper-air data obtained at stations of the Meteorological Section of the Signal Corps and of the Weather Bureau, shows that the distribution of weather elements agrees closely with the usual conditions as described by Bjerknes. The influence of the storm extended at least as high as 3 kilometers, as shown by kites and pilot balloons. There were high wind velocities, both at the surface and aloft, which gave rise to widespread dust storms in the Middle West. Eight maps show the distribution of pressure and winds (surface and aloft) from the 12th to the 15th, inclusive.

INTRODUCTION.

It is not often that the endless procession of low-pressure areas, sweeping across the United States from west to east, reveals a member so strikingly symmetrical, so intense, so persistent, and so remarkable in the distribution of cloudiness and precipitation as that of February 10 to 16, 1919. Appearing on the morning of February 10 off the coast of British Columbia, it moved southeastward into the United States, and by the morning of the 11th was centered in northern Nevada. The morning of the 12th found it centered at Denver, the 13th in eastern Kansas, the 14th in central Illinois, the 15th in New England, and the 16th found it over the Atlantic east of Newfoundland. Its greatest intensity was observed on the morning of the 13th at Kansas City, where the sea-level pressure was 28.90 inches. Previous to this time it had been gradually deepening, and in the remainder of its journey across the United States it diminished very slowly until it approached the ocean, when it appeared to intensify slightly because of the warmer air, the lesser surface friction over the water, and the increasing latitude. With such a strong horizontal gradient of pressure, it was natural that there should be high winds; and with such active circulation that there should be a strong surface temperature gradient. Therefore, because of the almost ideal characteristics of this Low, it has seemed worthy of study, not only as to surface weather, but also as to the winds aloft.

WEATHER AND WINDS.

Precipitation.—In several recent papers [1] on the general subject of forecasting weather, Prof. V. Bjerknes has outlined in a very lucid manner the way in which masses of cold and warm air interact in circulating about a barometric depression, based upon his observations in Norway. There are two distinct lines of discontinuity in the moving cyclone, *the steering line*, which is shaped like an inverted "S" and occurs in the eastern half of the depression, marking the front, at the surface, of a tongue of warm southerly air; and *the squall line*, which trails away from the center into the southwest quadrant of the cyclone, marking the rear of the intruding tongue of warm southerly air. Along the steering line the southerly air leaves the surface and overrides the easterly surface current in the northern part of the depression; along the squall line the cold northerly wind of the western side of the depression underruns the tongue of warm southerly air. Precipitation is closely related to these two lines: along the steering line the rain falls owing to the dynamic cooling of the southerly wind as it rises over the easterly, and along the squall line the rain falls from the southerly air, which is forced to ascend by the denser northerly wind. A third cause of rain is frequently operative also, namely, the convection caused by the convergence of winds within the tongue of southerly air.

The reason for outlining thus the observations of Prof. Bjerknes is to draw attention to the striking accord which exists in the performance of the cyclone in question. From the time the storm freed itself from the topographical hindrances of the Rocky Mountains the distribution of winds and precipitation during its eastward march conformed perfectly with the mechanical outline of Bjerknes. On the 12th, when the storm was centered

[1] The structure of the atmosphere when rain is falling. *Quar. Jour. Royal Meteorological Society*, April, 1920, pp. 119-140; abstract in Mo. Weather Rev., July, 1920, 48:401. The meteorology of the temperate zone and the general atmospheric circulation. *Nature* (London), June 24, 1920, pp. 522-524; abstract in later Review.

in Colorado, it had not yet attained sufficient control over the warm, moist air over the Gulf of Mexico to induce precipitation as usual in the region east of the center. But Texas, Louisiana, Arkansas, and Oklahoma were covered with clouds, and farther north, in Kansas, Missouri, and Illinois, the sky was partially covered. During the succeeding 24 hours, however, precipitation was general throughout the Mississippi Valley and Southern States. But at the time of observation (8 a. m., 75th mer. time) rain was falling along a strip extending from eastern Georgia and South Carolina northwestward into Indiana, Illinois, and Iowa. This was caused by ascending southerly winds, which at the surface were strong. Rain and snow were also falling in southern Kansas and Oklahoma along the squall line. This relative distribution of precipitation moved continuously forward into new regions of the country, owing to the eastward movement of the cyclonic center. The observations on the upper winds, which are given later, also show this eastward progression. It may be of interest to quote excerpts from the weather-map synopses prepared by Dr. Frankenfield on the mornings in question:

February 12:

Low pressure prevails generally this morning, except in the Pacific States, and there is a marked disturbance central over eastern Colorado. Precipitation continued general west and northwest of the storm center, but as yet there has been none to the eastward and southward. * * *

February 13:

The most severe storm of the present winter is central this morning over northwestern Missouri with a barometer reading of 28.90 inches at Kansas City. The storm influence covers the entire country east of the Rocky Mountains, and there are general rains in the Southern States, the great central valleys, and the southern upper Lake Region, and rains and snows in the Plains States. * * *

February 14:

The barometer is still abnormally low over the eastern half of the country, with a very slow movement of the center of disturbance, which is over Illinois this morning. General rains continue over the low area, with also considerable snow on its northern and western boundaries. * * *

Temperature.—The effect of the cyclone with respect to temperature was most marked on the 12th, 13th, and 14th, because on these dates the storm was so situated as to produce the greatest contrast of temperature between the front and rear. Before the storm was centered in Colorado the temperatures over the eastern half of the United States were quite even, the difference between the Gulf region and the Great Lakes being not over 11° C. The influence of the LOW upon the temperature became strongly marked, however, as soon as the storm crossed the Rockies.

A line drawn through the center of the depression in a general northwesterly direction lies nearly normal to the isotherms. Measuring along such a line on the several succeeding mornings we discover large differences in surface temperature. For example, on the 12th, between Galveston, Tex., and Yellowstone Park, Wyo., there was a difference of temperature of 20° C.; on the 13th, between Mobile, Ala., and Rapid City, S. Dak., there was a difference of 21° C.; and between Jacksonville, Fla., and Moorhead, Minn., on the 14th there was a difference of 25° C. By the next morning the center of the LOW was so far advanced that it is not possible to obtain temperatures in its southeast quadrant, but between Jacksonville and Moorhead the difference of temperature had increased to 28° C.

Following the storm low temperatures were prevalent over the eastern United States as a consequence of the northerly winds in the rear of the storm.

Upper air observations.—The upper air observations made at this time were largely in the hands of the Meteorological Section of the Signal Corps, which had stations at many of the flying fields and artillery camps. These observations were made with pilot balloons and clouds, the latter being non-instrumental. The Weather Bureau had at that time six kite stations, at several of which pilot balloon observations were also made. Pilot-balloon observing during the passage of a LOW is, owing to the widespread cloudiness and consequent early disappearance of the balloon, rather unsatisfactory. The data presented here and in the accompanying charts are gathered from the records of these Signal Corps stations and the aerological stations of the Weather Bureau. The cloud data from the regular stations of the Weather Bureau were not used because of the fact that the Signal Corps stations made more frequent complete observations, often every two hours; moreover, the meteorologists in charge of nearly all these stations submitted transcripts of their records during this period, which greatly facilitated the organization of the data. To have secured an equivalent amount of information from the original forms would have involved labor incommensurable with their value as additional material.

Over- and underrunning winds.—One of the interesting studies to be made with upper air wind data is that concerning the overrunning and underrunning of winds. An example is to be found on the morning of the 12th. The steering line, as shown by the very short wind arrows on Chart I in red, extends eastward from the center of low pressure through southern Nebraska and Iowa, across central Illinois to a point in central Indiana, where it was influenced by a secondary LOW centered over southern Lake Michigan. This line, according to Bjerknes, may be considered as the line along which the winds of southerly component leave the surface and rise up over the current of easterly winds. The kite observations at Drexel, Nebr., and Ellendale, N. Dak., afford interesting material. Drexel lies not over 50 kilometers north of the position of the steering line. Here there was observed a turning from ESE. to SE. at an altitude of 1,000 meters above sea level, or 604 meters above the station. With this shift of direction was associated an inversion of temperature, part of which may undoubtedly be attributable to the southerly wind, although the inversion was enhanced by the low temperature of the ground itself. The record shows a surface temperature of 0.6° C. (33.1° F.), a temperature at 104 meters above the station of 3.9° C. (38.8° F.), and at 604 meters above the station of 11.0° C. (51.8° F.). From a point 39 meters higher the temperature fell slowly for 500 meters and then more rapidly.

At Ellendale the same morning we find the wind becoming SE. from E. between 1,200 meters and 1,500 meters above sea-level, or between 706 and 956 meters above the station. Estimating the point on the steering line where the air, rising in a northwesterly direction, would reach Ellendale, we find the horizontal distance it would have to traverse to be about 600 kilometers. It is now possible to estimate the rate of ascent of the southerly air. Estimating the height of the point where the air left the surface as about 390 meters above sea level, it is found that the ratio of vertical to horizontal motion of the air at Drexel is about 1 to 71, and at Ellendale is about 1 to 500. Bjerknes, in Norway, using the formula of Margules,[2] finds that there is an "inclination, as a rule, of an order of magnitude between 1 in 50 and 1 in 100."

[2] Margules, Max: On the energy of storms. English translation by Cleveland Abbe, in the Mechanics of the Earth's Atmosphere, Smithsonian Misc. Coll., vol. 51, No. 4.

It is seen that this agrees with the value at Drexel, but not at Ellendale. The distance from the steering line to Ellendale, 600 kilometers, is a greater distance than Bjerknes has to deal with in Norway, whereas the distance to Drexel, 50 kilometers, is quite comparable with those in Norway.

When attention is paid to the moisture content and temperature of the air aloft in the occurrence of overrunning winds at various aerological stations, the amount of precipitation to be expected over the region in question can be computed. Supposing two stations, such as Drexel and Ellendale, show the progress aloft of an ascending layer of warm, moist air. The amount of rain that will fall out of a section of such a layer in traveling from Drexel to Ellendale will be equal to the difference in the amount of moisture contained as it passed over the two stations. This rainfall is, owing to the cooling of the air, largely as a result (1) of rising over the wedge of cold air at the surface, and (2) of rising on account of lateral convergence within the southerly wind itself. The amount of rainfall due to the first may be computed roughly from the cooling resulting from the rise of air up the slope from one station to the other. That due to the second would be approximately the difference between the total and that computed for the first. The placing of such data in the hands of the forecaster in time and in such a form as to be of service in his work should be of assistance in the forecasting of precipitation. In the case of February 12 the region wherein precipitation would ordinarily be expected was clear. The Drexel observation shows that both the lower and overrunning air were of low relative humidity, averaging about 50 per cent and 26 per cent, respectively. At Ellendale the values were about 92 per cent and 63 per cent, respectively. These data are sufficient to show why there was no precipitation. If there had been available, on the following day, data from a series of four or five stations, extending from Leesburg, Ga., through Royal Center, Ind., to northern Michigan, it would have been possible to compute the amount of rainfall over that region.

The charts show all the available aerological data. In red are given the surface wind directions (small arrows), the sea-level pressure, and the wind directions at 500 meters above sea level (large arrows). The charts present the morning and evening conditions for the four days February 12 to 15, inclusive. It should be remarked that in the case of the afternoon maps the upper air observations which represent conditions at about 3 p. m. (seventy-fifth meridian time) are plotted over barometric and surface wind conditions for 8 p. m. This discrepancy of five hours between the upper wind directions and the surface probably is not significant because of the moderate rate of movement of the depression. The data for the wind directions at the 1, 2, and 3 kilometer levels are shown in black arrows—solid for 1 kilometer, dashed for 2 kilometers, and dotted for 3 kilometers. Whenever two or all of these levels had wind of the same direction, the fact is indicated by two or three heads on the arrow. Wherever the observation is upon clouds alone, a black symbolic arrow, varied for the different cloud types, as shown in the legend, is placed as near the station as possible.

It is seen from the charts that the wind directions to at least 2 kilometers conform quite closely to the sea-level distribution of pressure. It is the normal thing for winds at 3 kilometers in cyclones to show quite a decided westerly tendency. Such is the case here where observations to that height were made. Since there were practically no observations in the northern part of the LOW, it is difficult to know whether the westerly tendency was also present there, where surface winds were easterly.

Mr. W. R. Gregg, in discussing this question, has pointed out the fact that at Drexel on the morning of the 12th the observations showed an easterly component as high as 3 kilometers; in fact, the wind was almost parallel to the sea-level isobars. Above this height, however, there was a veering to southwest. The easterly component at Ellendale, while still in evidence at 2 kilometers, had diminished considerably in strength. The temperatures at Ellendale, both at the surface and aloft, were lower than at Drexel, with the result that with increasing altitude there was a diminishing pressure gradient between the two stations. Indeed, at 2 kilometers above sea-level at both stations the pressure as recorded by the meteorographs was identical, 781 mm. Above this height the gradient was the reverse of that at the surface. Therefore, in all probability there was a shift to southwest slightly above 2,500 meters. This conclusion is also supported by the fact that the kite flight was a low one owing to diminishing winds.

Wind velocities.—Such steep horizontal pressure gradients as those indicated by the sea-level distribution of pressure may be expected to yield quite high velocities. It will be of interest to note the speeds actually observed both at the surface and aloft and compare them with the gradient velocity, which may be easily computed,[3] assuming the sea-level gradients to be influential at least as high as 500 meters. The fact that this cyclone is characterized so strongly by the smoothness and concentric nature of the isobars would suggest that the agreement between the observed and computed velocities should be close.

A few of the highest surface velocities recorded during the passage of the LOW are given in Table 1.

TABLE 1.—*Current and maximum*[1] *velocities of surface wind.*

Station.	Feb. 12.		Feb. 13.				Feb. 14.	
	8 p. m.		8 a. m.		8 p. m.		8 a. m.	
	Current.	Maximum.	Current.	Maximum.	Current.	Maximum.	Current.	Maximum.
	m/s.	*m/s.*	*m/s.*	*m/s.*	*m/s.*	*m/s.*	*m/s.*	*m/s.*
Cheyenne	17.0	20.6			11.6	21.5		
Huron					13.4	18.8		
North Platte			19.7	21.5	14.3	23.2		
Dodge City			17.0	18.8				
Wichita					18.8	23.2		
Oklahoma City					8.0	26.8		
Amarillo					6.3	17.9		
Abilene	18.8	20.6						
El Paso	17.9	26.8	11.6	19.7				
Del Rio			13.4	17.9				
San Antonio			8.0	18.8				
Milwaukee			13.4	16.1	16.1	21.5		
Terre Haute							11.6	21.5
Evansville					12.5	21.5		
Little Rock					14.3	17.9	13.4	17.9
Vicksburg							8.0	17.9
Memphis					17.9	23.2	9.8	25.0
Pensacola					10.7	19.7		

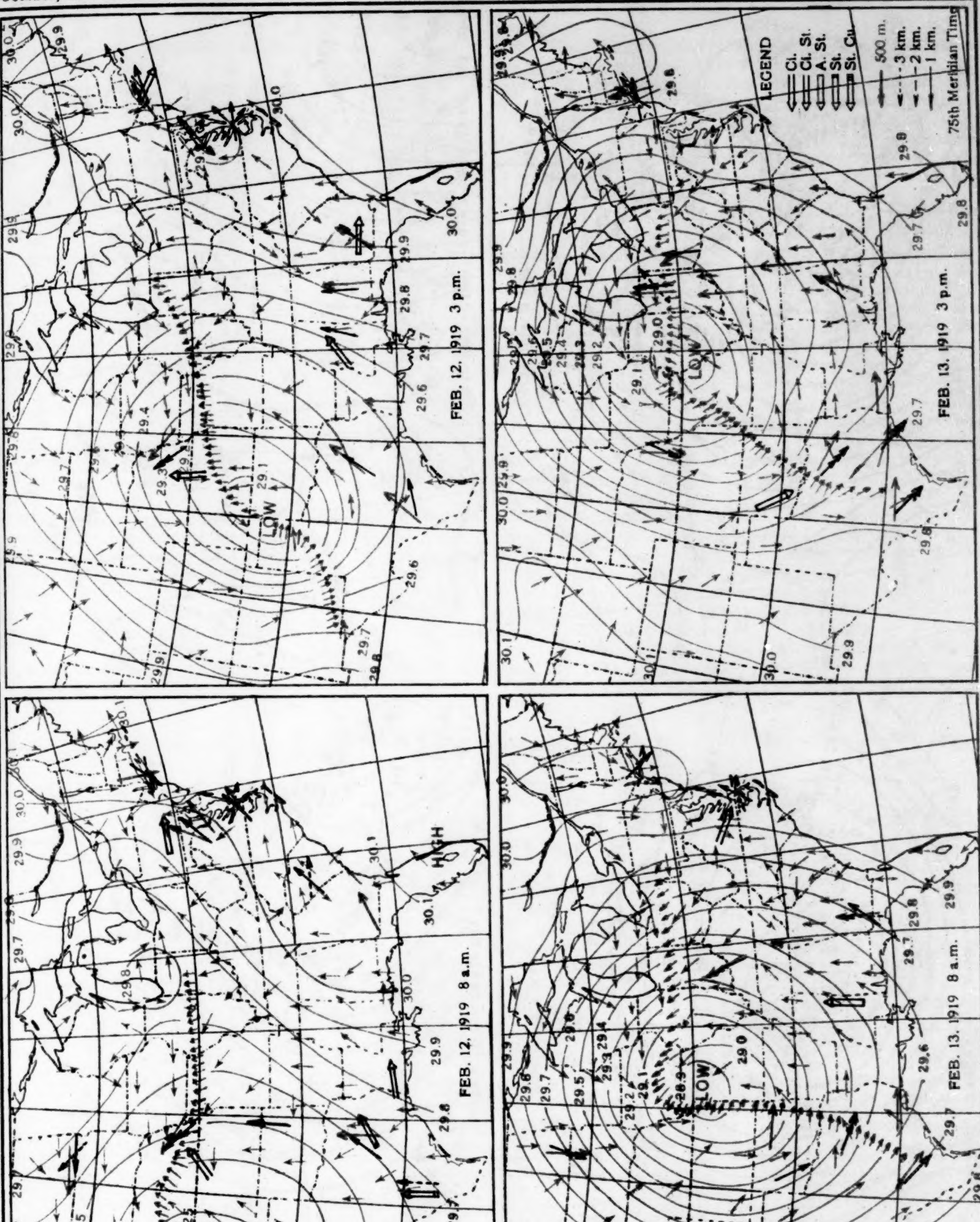
[1] The maximum for a five-minute period during the preceding 12 hours.

Comparisons between the computed velocity and the observed for several stations are presented in Table 2.

First, it is seen that practically all the differences in the 500-meter column are of negative sign, indicating that, on the whole, the velocities at 500 meters were less than those computed. The 1,000-meter column, on the other hand, shows a positive tendency, indicating that the observed speeds were, on the whole, greater than the computed values. From this it may be inferred that the gradient velocity occurred between the 500-meter and 1,000-meter elevations above sea-level, or between 350 meters and 600 to 1,000 meters above the stations.

[3] Humphreys, William J.: The physics of the air. Franklin Institute, Philadelphia, 1920, pp. 139, 140. Cf. Marvin, C. F: The law of the geoidal slope and fallacies in dynamic meteorology, this REVIEW, pp. 570-573.

C. L. M. Chart I. Winds at various Heights and Pressure at Sea-level.



C. L. M. Chart II. Winds at various Heights and Pressure at Sea-level.

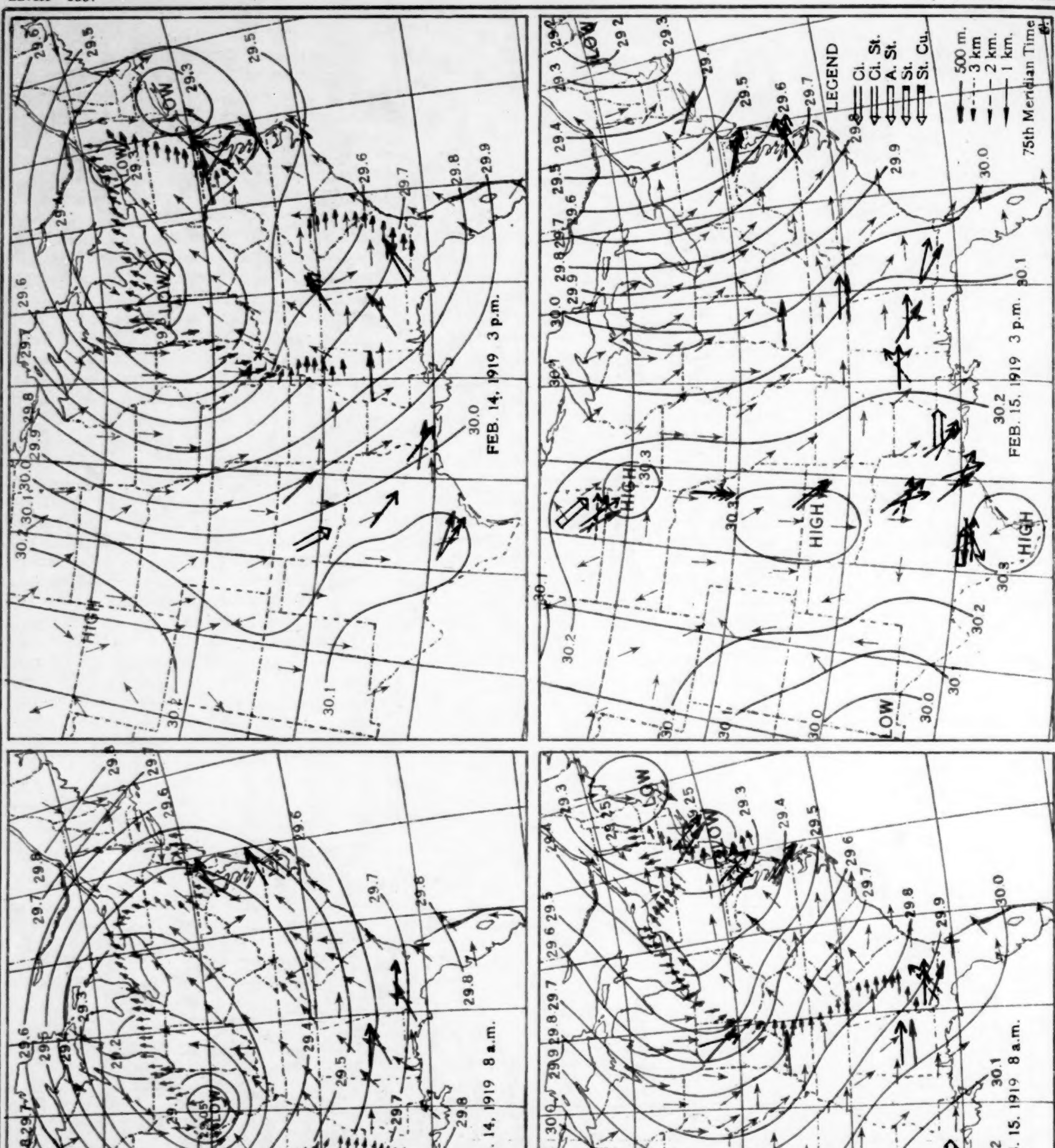


TABLE 2.—*Comparison of observed and computed wind velocities.*

Date.	Time.	Station.	Computed velocity.	Observed velocity.		Observed minus computed.	
				500 meters.	1,000 meters.	500 meters.	1,000 meters.
	A. M.		*m/s.*	*m/s.*	*m/s.*	*m/s.*	*m/s.*
Feb. 12...	8	Ellendale.....	22	[1] 10	10	−12	−12
		Drexel.........	13	[1] 12	14	− 1	+ 1
		Broken Arrow	20	[1] 24	30	+ 4	+10
		Groesbeck.....	20	21	28	+ 1	+ 8
Mean difference..........			....	....	....	− 2	+ 7
Feb. 13...	8	Ellendale.....	22	[1] 14	15	− 8	− 7
		Groesbeck.....	28	13	20	−15	− 8
		San Antonio..	11	19	18	+ 8	+ 7
		Leesburg......	23	21	22	− 2	− 1
Mean difference..........			....	....	....	− 4	− 2
Feb. 14...	8	Ellendale.....	16	[1] 20	21	+ 4	+ 5
		Groesbeck.....	17	16	16	− 1	− 1
		Leesburg......	17	16	20	− 1	+ 3
Mean difference..........			....	....	....	+ 1	+ 2
Feb. 15...	8	Royal Center..	16	[1] 13	15	− 3	− 1
		Montgomery..	15	10	11	− 5	− 4
		Fort Monroe..	13	16	20	+ 3	+ 7
Mean difference..........			....	....	....	− 2	+ 1

[1] The data for Ellendale, Drexel, Broken Arrow, and Royal Center are given for a level 350 meters above the station, instead of 500 meters above sea level because of the fact that they are over 200 meters above sea level, and thus the 500 meter above sea-level elevation would be so near the surface at those statons as to include considerable influence of friction. All other values in the table are for the heights indicated above sea-level.

The large negative departure of Ellendale on the 12th is probably to be accounted for by the decreasing gradient pointed out above. Conversely, the excess of observed over computed velocities at Broken Arrow and Groesbeck can be explained on the basis of an increasing gradient aloft, which is produced by the smaller vertical decrease of pressure in the heated air of southern latitudes.

It is also evident that the best agreement occurred in those cases where the homogeneous northerly winds were blowing, on the 14th and 15th. The greatest discrepancies, on the other hand, occur where the winds are not homogeneous—that is, where there is over- and under-running of winds. The reason for these discrepancies is probably as follows: In the case where a cold easterly or northeasterly wind at the surface is wedging itself under a southerly current, there is a region, bounded on the south by the steering line, in which the reduction of pressure to sea-level is influenced by the temperature argument. That is to say, the temperature at stations north of this line is abnormally low owing to the importation of cold air, with the result that the reduced pressures are somewhat greater than they should be. Thus, the weather map indicates a gradient wind which does not exist. The mention of this point must naturally lead to the repetition here of a point which was made in an earlier paper,[4] namely, that if we are to be able to forecast winds aloft for the use of aviation, or, as in this case, to determine the gradient velocity from computation based upon isobaric maps, those maps *must* represent the pressure distribution at the level under consideration. Sea-level maps do not represent such a level, and it is only a fortunate circumstance which permits us to approximate the speed of the winds at a few hundred meters above the surface with a fair degree of accuracy.

Clouds.—The following table gives for four stations the succession of clouds as observed during the passage of the LOW. These observations were made at Signal Corps stations every two hours, from 6 a. m. to 8 or 10 p. m. The stations presented here, Kelly Field, Tex.; Ellington Field, Tex.; Gerstner Field, La.; and Hazelhurst Field, Long Island, N. Y., are not as well distributed with respect to the depression as one might wish, but they serve as good examples of the succession of clouds in the particular portions of the storm in which they were located.

TABLE 3.—*Succession of clouds as observed at two-hour intervals during the passage of the* LOW *at Kelly Field, Ellington Field, Gerstner Field, and Hazelhurst Field, given in amount (tenths of sky covered), kind, and direction.*

Station.	Date.	Time.								
		6 a. m.	8 a. m.	10 a. m.	12 noon.	2 p. m.	4 p. m.	6 p. m.	8 p. m.	10 p. m.
Kelly Field (San Antonio), Tex.	Feb. 10	4 St.......SW	10 St.........S	10 St.......SW	10 Nb.........S	10 St..........S	10 St.......SW	10 St.......SW	10 St. Cu.....S	10 St. Cu.....S
	Feb. 11	Dn. fog (?)....	Dn. fog.......S	Dn. fog....SW	10 St.......SW	10 St........SW	10 St.......SW	10 St. Cu.....S	10 St. Cu.....S	10 St. Cu.....S
	Feb. 12	10 St. Cu....S	10 St. Cu.....S	FewA.Cu..SW 9 St. Cu......S	FewA. Cu..SW Few Cu....SW	1 St. Cu....SW Few Cu....SW	2 f St.......SW Dust..........	None..........	None..........	None.
	Feb. 13	None..........	None..........	None..........	None..........	None..........	None..........	None..........	None..........	None.
	Feb. 14	None..........	None..........	None..........	None..........	None..........	None..........	None..........	None..........	None.
	Feb. 15	4 Ci.........W	9 Ci. St.....W	9 A. St......W	6 A. St.....SW	8 A. St.....SW	10 A. St......W Few A. Cu. .W	10 A. St.....W Few A. Cu. .W	10 A. St.....W	10 A. St.....W
	Feb. 16	10 A. St.....S	10 A. St.....S	10 A. St......S	10 A. St....SW	10 A. St......S	10 A. St......S	10 A. St....SE	10 Nb.?.......	10 St. ?
Ellington Field (Houston), Tex.	Feb. 10	3 St. Cu.....W	8 St. Cu.....W	Few Cu...SW	6 Cu.......SW	10 St. Cu...SW	10 St. Cu...SW	10 St. Cu...SW	10 St. Cu...SW	
	Feb. 11	10 St. ...WSW	10 St. ...WSW	10St.Cu. WSW	8 St.Cu..WSW	6 Cu.........W	7 Cu.........W	8 St.Cu..WSW	6 A. Cu....SW	
	Feb. 12	10 St. ....S	10 St.........S	10 St.........S	10 St..........S	10 St..........S	10 St..........S	10 St..........S	10 St..........S	
	Feb. 13	10 St.........W	10 St.........W	10 St.........W	Lt. haze....W	Lt. haze....W	Lt. haze....W	Lt. haze....W	Lt. haze....W	
	Feb. 14	Lt. fog .....W	Lt. fog......W	Lt. haze....W	Lt. haze....W	Lt. haze....W	Lt. haze....W	Lt. fog.. WNW	Lt. fog......W	
	Feb. 15	Few A. St. .W	Few A. St...W	5 A. St......W	7 A. St......W	6 A. St......W	6 A. St......W	3 A. St......W	Few A. St...W	
	Feb. 16	9 A. St. ...SW 1 A. Cu....SW	9 A. St.....SW 1 A. Cu....SW	10 A. St....SW	10 A. St....SW	10 A. St....SW	10 A. St....SW	10 St.Cu. WSW	10 St.Cu. WSW	
Gerstner Field (Lake Charles), La.	Feb. 10	10 A.St. WNW	3 Ci. St.. WNW 5 A.St.. WNW	3 Ci. St.. WNW	Few A. St...W	2 A. St.......W	2 A. St.......W FewSt.Cu.SSE	1 A. St.......W	10 A. St . WSW	10 A.Cu. WSW
	Feb. 11	1 Cu.........W Lt. fog ....E	10 St. ....W Lt. fog.......W	3 Cu..........W	8 Cu.......SW	8 Cu.......SW	4 Cu.......SW	FewA.St.WSW 2 St.........W	10 St.........W	10 St.........W Lt. fog.....SW
	Feb. 12	9 A.St...WSW 1 St.......SSW	4 A.Cu.. WSW 3 Ci. St.. WSW	1 A. Cu.. WSW 3 St.Cu...SSW	10 St. Cu.....S	7 St. Cu....SW 3 St.......SSE	3 St. Cu....SW 7 St.......SSE	10 St......SSW	10 St......SSW	10 St.....SSW
	Feb. 13	3 A. St...W(?)	Lt. haze.......	Lt. haze.......	Lt. haze.......	Lt. haze.......	Lt. haze.......	None..........	None..........	None.
	Feb. 14	Lt. haze.......	Lt. haze.......	Lt. haze.......	None..........	Few St. Cu..W	None..........	None..........	None..........	None.
	Feb. 15	None..........	Few Ci.....W	1 Ci.........W	8 Ci.........W	9 Ci.........W	9 Ci. St......W Few Ci..Cu. W	8 Ci. St......W Few Ci. Cu.. W	8 Ci. St......W	8 Ci.St......W
	Feb. 16	3 Ci. St. ....W 1 Ci. Cu. ....W	2 Ci. St. ....W 7 A. Cu......W	9 Ci. St. ....W 1 Ci. Cu.....W	8 Ci. St. ....W	9 Ci. St. ....W Few Ci. Cu..W	2 Ci. St. ....W 6 A. Cu......W	10 A. St. ....W	8 A. St......W 2 St. Cu......W	8 A. St......W 2 St. Cu.....W
Hazelhurst Field (Mineola), N. Y.	Feb. 10	3 Ci. St......W	4 Ci. St......W	1 Ci. St......W	1 A. Cu......W	2 A. Cu....NW	2 A. Cu....NW 2 St. Cu......N	1 St. Cu......N	None	None.
	Feb. 11	None..........	None..........	None..........	None..........	None..........	None..........	2 Ci. St....SW	7 Ci. St....SW	10 Ci. St...SW
	Feb. 12	10 St.......NE	10 A. St.....W	10 St.......SW	10 St.......SW	10 St......NW	10 St......NW	10 St......NW	10 St.......SW	10 St.......SW
	Feb. 13	3 Ci. St......W	2 Ci. St....NW 3Ci. Cu....NW	3 Ci. St......W	3 Ci. St......W	7 A. St......W	10 A. St.....W	10 St.......NE	10 St.......NE	10 St.......NE
	Feb. 14	10 St. ....E	10 St.........E	10 St.........E	10 St.........E	10 St.........E	10 St. E.......	10 St.........E	10 St..... .NE	10 St.......NE
	Feb. 15	10 St. ....NW	10 St......NW	10 St......NW	10 St......NW	10 St......NW	10 St.Cu. WNW	10 St. Cu....W	10 St. Cu....W	10 St. Cu....W
	Feb. 16	10 St. Cu.. NW	9 St. Cu...NW	6 St. Cu....NW	FewSt.Cu. NW	FewSt.Cu. NW	None..........	None..........	None..........	None.

[4] Meisinger, C. LeRoy: Preliminary steps in the making of free-air pressure and wind charts. MO. WEATHER REV., May, 1920, 48: 251-263.

Dust storms.—In the Middle West, about the middle of the period in question, dust storms were reported from many stations, and by noting the dates upon which dust was observed a fair idea of its progress can be obtained. The Signal Corps meteorological station at Fort Sill, Okla., reports that on the morning of the 12th, with a surface wind of 5.4 meters per second from the southeast and a wind of 17.9 meters per second from the southwest at an altitude of 700 meters above the station, the dust began to fill the air. The barometer was falling rapidly. This condition continued until about 2:30 p. m., at which time the air was filled with dust and the the sky was obscured. The moon that night was seen through a very heavy layer of dust. The station at Kelly Field (San Antonio), Tex., reported: "A severe wind and dust storm approached this field from the west about 3:15 p. m. The extreme velocity measured at this station on the surface was 13.4 meters per second at 3:20 p. m. No rain fell in the immediate vicinity, although it was observed raining 3 or 4 miles to the northwest at 3:07 p. m." Other stations reporting the phenomenon were Gerstner Field (Lake Charles), La., and Payne Field (West Point), Miss. The report from the former station on the 13th says: "A light haze became visible about 7 a. m. It was rather high, but gradually became lower and thickened. By 11 a. m. it had reached the surface. About 2 p. m. it became heavy and the dust particles were larger. They began to settle on objects where the air was quiet, and they irritated the nasal passages. About 4 p. m. the wind changed from WSW., where it had been most of the morning and early afternoon, to W. and WNW. The haze was dissipated rapidly and had disappeared by 4:30 p. m. At night a large diffused light area around the moon showed the presence of an unusual amount of dust in the air." The latter station, Payne Field, noted a "dry fog" or haze on the 13th. The sun was visible through it, but it is described as "silver white."

At various stations in Iowa and Illinois the dust was observed. At Alexander, Ill., the dust was accompanied by rain, causing the precipitation of what was described as "red mud." This occurred on the morning of the 13th. At Des Moines and at St. Charles, Iowa, samples of the dust were collected and were subjected to examination by Jacques W. Redway, of Mount Vernon, N. Y. Concerning the Des Moines specimen he says:

* * * The essential part of the content consists of rounded grains of white quartz sand, and reddish, jaspery quartz sand. A few particles of crystalline fragments resembling calcite are in evidence. * * * It is difficult to account for the spherules of iron. They were not noticeable at first, but the pole of a magnet collected a considerable number of them. Meteoric iron has not been much in evidence in atmospheric dust since 1914; moreover, the spherules in the Des Moines specimen are materially different from any hitherto collected at this laboratory. In color and appearance they much resemble emery-wheel dust. Similar spherules are sometimes blown out of smelter stacks when a strong blast is employed. According to Mr. Reed (Weather Bureau official at Des Moines), there are no smelters in the vicinity of Des Moines. Mr. Reed also noticed that some of the dust clung to the ironwork of his instrument supports.

A later letter from Mr. Reed stated that while there are no smelters in that vicinity there are several small foundries, one of which is four or five blocks southwest of the station. It is possible that the iron particles may have come from that source.

It seems probable that this dust may have been picked up by the high winds in the southwest, carried eastward and spread through the atmosphere in the rear and southern portions of the storm.[5]

CONCLUSION.

This study again brings to our attention the absolute necessity for aerological data. One can not be content to study weather without a knowledge of what is going on in the third dimension. This paper has pointed out how current aerological data can be put to good use in forecasting precipitation; but the greatest good can not be realized until there exists an adequate number of aerological stations in the United States. These upper-air data are indispensable and the establishment of more stations is certain to lead to an ever increasing return upon the investment.

[5] Winchell, A. N., and Miller, E. R.: The dustfalls of March, 1918. MONTHLY WEATHER REVIEW, November, 1918, 46:502-506.

ECONOMIC RESULTS OF DEFICIENT PRECIPITATION IN CALIFORNIA.

By ANDREW H. PALMER, Meteorologist.

[Weather Bureau, San Francisco, Calif., October, 1920.]

SYNOPSIS.

Because of markedly deficient precipitation in northern and central California during the past four rainy seasons serious loss resulted during the dry season of 1920. Streams reached the lowest stages on record. The Sacramento River at Sacramento fell below mean sea level, and the current of the stream was reversed in direction. The saline waters of San Francisco Bay encroached upon rich agricultural lands of the delta region, reducing the vegetable crops, drove the dairy industry to other regions, and threatened irreparable damage to alluvial soils through the infiltration of salt water through seepage. For domestic use fresh water had to be transported on barges across the bay. The teredo, or "ship worm," a minute salt-water organism, did great damage to wooden structures. In the interior valleys the water problem has passed from one of too much water to one of too little. The average yield per acre of many crops was reduced in 1920 because of deficient moisture. Rice growers felt the drought keenly, because of the large water requirements of rice. Litigation over water rights has ensued, and additional legislation is apparently needed to meet new conditions. Hydroelectric power shortage resulted in power restrictions and higher rates for electricity, thus raising the cost of living. Wells went dry because of the lowered level of ground water. Forest fires were more frequent and destructive than in past years, owing to the parched condition of the forests. Partial relief from the drought came as a result of copious showers in October, 1920. The storage and utilization of fresh water is one of the most important problems confronting California to-day.

INTRODUCTION.

Comparatively few people residing in the central and eastern portions of the United States appreciate the value of the generous precipitation received in those regions. In the West and Southwest, and particularly in California, water is wealth, and irrigation water is aptly termed "the lifeblood of the State." Since successful agriculture requires a minimum of 15 to 20 inches of water a year, vast regions in the West, where the annual precipitation is normally below those amounts, are largely dependent upon artificial irrigation. Most of these irrigation systems receive their supplies from the relatively heavy precipitation of the mountain regions, and the water is conducted through artificial canals from streams or from natural or artificial reservoirs. In designing such systems due allowance is made for abnormally heavy or deficient precipitation. But when abnormally light precipitation recurs for three or four consecutive years the inevitable water shortage brings economic results which cause a community to recognize the necessity of an adequate water supply.

Northern and central California have received deficient precipitation during the past four rainy seasons. Disaster seemed to threaten when the season 1919–20 started out to be the driest on record. In February, 1920, the public utility commission of the State of California organized a "water-conservation conference," composed of the various national and State agencies concerned with the water problem.[1] At meetings of the conference the problem was discussed in detail, the public was warned of the impending shortage, and every effort was made to conserve water. Fortunately March and April brought abundant precipitation, but an insufficient amount to make up the deficit. Mr. Paul Bailey, civil engineer, was appointed watermaster by the conference, and he went immediately to the Sacramento Valley to urge water conservation. He remained there the greater part of the summer, carrying out measures tending toward an equable distribution of the limited water available. As the growing period of the season of 1920 is now over, and the early autumn rains of the season of 1920–21 have begun, it is believed that a brief résumé of the results of the deficient precipitation will be of interest from a scientific and an economic standpoint, as well as from the viewpoint of the engineer.

STREAMS REACH RECORD LOW STAGES.

During the summer of 1920 nearly all streams in northern and central California reached the lowest stages on record, and some of the smaller streams dried up entirely. At Rio Vista, on the Sacramento River, and 70 miles inland from the Golden Gate, the river fell to a point more than a foot below mean sea level on August 24, and remained at about that stage for five consecutive days. At Sacramento, 90 miles inland from the Golden Gate, the Sacramento River on August 2 fell to a point 0.5 foot below mean sea level, the lowest stage on record.

Physiographically San Francisco Bay is a drowned or submerged valley, being the lower reaches of the Sacramento-San Joaquin River. The region has been submerged during geologically recent times, and there is evidence that the subsidence is still in progress. The water of the bay is saline, and under normal conditions the water of the two large streams which flow into it is fresh. But because of the low stages of these streams during the summer of 1920 the flow in the lower portions was actually reversed at times, and the salt water flowed inland, encroaching upon rich agricultural lands which in the past had been irrigated by seepage and the pumping of fresh water from the natural flow of these streams. For many years this favored delta region has been termed "San Francisco's bread basket," for every year there were grown in this region 20,000 carloads of potatoes, celery, tomatoes, asparagus, and various deciduous fruits. Moreover, it is a rich dairy region, as the summer fogs keep the pastures green throughout the summer. While in past years flood was the single source of fear, in 1920 the curse of salt water markedly reduced the crops, and threatened irreparable harm through the infiltration of salt in the rich alluvium. The acreage of vegetable crops was reduced in anticipation of the water shortage. Dairymen moved their cattle to more attractive regions.

As the summer progressed the saline water moved farther and farther up the river. At the sugar refinery of the California-Hawaiian Sugar and Refining Co., at Crockett, where 400,000 tons of cane sugar are manufactured annually, it was found necessary to transport fresh water by barge across the bay in order to continue operations. Subsequently the saline water reached Antioch, still farther inland, and pipes and boilers in homes and factories were eroded and later fell to pieces. At a $2,500,000 paper-board mill situated near Antioch, and which required 1,500,000 gallons of fresh water per day for operation, barges for carrying fresh water were also put into use to prevent a complete shutdown. It cost the town of Antioch $15,000 a month for domestic water supply. Residents were placed on a water ration of five gallons per day per family.

[1] See MONTHLY WEATHER REVIEW, March, 1920, 48: 156–157.

THE "SHIP WORM" ACTIVE.

The encroachment of saline water into regions previously unaffected introduced a destructive force of great economic consequence. This is the teredo, a minute, marine organism, popularly known as the "ship worm," which survives only in water having a salt content between 0.5 and 4 per cent. (Water in the North Pacific Ocean is 3 to 4 per cent salt.) This organism burrows into wood which is in contact with the salt water in which it lives, and eventually the "honeycombed" wood structure is so weakened that it collapses. The spread of the teredo through the encroachment of the saline water of San Francisco Bay did great damage to wooden structures. On September 25, 1920, a wooden wharf at Port Costa, 1,000 feet long and valued at $5,000, collapsed as a result of teredo operations, and there were precipitated into the bay $10,000 bags of freshly harvested barley, valued at $25,000. Other wharves in the vicinity were subsequently abandoned. The Southern Pacific ferry, which transports railroad trains across the stream at this point, had to be dry-docked, and the wooden bottom was replaced with a new copper-covered bottom.

It is conservatively estimated that the teredo did damage exceeding $1,000,000 in amount in the San Francisco Bay region during the summer of 1920. In order to prevent further loss, property owners on the water front subscribed $25,000 to secure the services of experts to study the problem and to recommend measures of combating further depredations of this organism. Representatives of the Forest Products Laboratory, of Madison, Wis.; of the University of California, of Berkeley, and of the Wood Preservation Association, of San Francisco, are at present engaged in this research.

DROUGHT EFFECT IN THE INTERIOR VALLEYS.

Outside the bay and delta regions the economic losses resulting from the deficient precipitation were not less apparent. The Sacramento-San Joaquin Valley is a fertile region, the seat of northern California's agriculture, the crops consisting principally of grain, alfalfa, and fruit. The San Joaquin Valley has become the richest raisin and grape producing region in North America. During recent years the flood plain of the Sacramento Valley has become a valuable rice-growing district.

For more than a quarter of a century agricultural, irrigation, engineering, and political leaders have urged that some comprehensive scheme be carried out to get the maximum use of the Sacramento Valley's water and to minimize damages done by it. The flood menace compelled first attention. In 1894 C. E. Grunsky and Marsden Manson urged flood control by: (1) Rectification of channels; (2) overflow weirs at certain points; and (3) leveed by-passes to carry the overflow. This proposition has been carried out to a large extent by the State reclamation board. However, this plan had no

relation to irrigation or power; and the problem has lately passed from one of too much water to one of too little.

The scope and nature of the work which may be done to increase the low-water flow was recently indicated by Fred H. Tibbetts, representing the Association of Northern California Irrigation Districts, who advocated: (1) Diversion into the Sacramento River of water from other watersheds, such as the Klamath River; (2) storage of flood waters now running to waste during winter and spring; (3) prevention of advance of salt water from the bay, thus rendering usable the flow now necessary to insure fresh water in the delta; (4) canalization of the Sacramento River by a system of locks to decrease the flow necessary for navigation.

In February, 1920, Prof. Frank Adams, of the United States Department of Agriculture and the University of California, proposed at a meeting of the Sacramento Valley Department Association that the entire valley be organized by the State legislature into a single State conservation and flood-control district, merging flood control, reclamation, drainage, and irrigation into a single, unified projects.

In harmony with that suggestion, there was launched in September, 1920, a project, the engineering features of which were designed by R. B. Marshall, of the United States Geological Survey, whereby through the construction of one gigantic storage and irrigation project there would be reclaimed an additional 12,000,000 acres of land. The Marshall plan proposes the storage of enough water in the Sierra Nevada Mountains to fill reservoirs sufficient to reclaim all the irrigable lands in the Sacramento, San Joaquin, and other adjacent valleys, and the distribution of these waters through a system of canals. It is estimated that the project would cost between $600,000,000 and $700,000,000 and would add billions of dollars to the wealth of the State. As an indication of the certain success of the project, it is pointed out that the crops from the Roosevelt project in Arizona during 1919 alone were of value twice greater than the entire initial cost of the engineering works connected therewith. California can support a population of 30,000,000 people with the proper storing and distribution of water.

Because of generous rains during March and April, 1920, the agricultural interests of northern California did not experience the disaster which threatened earlier. However, the yield per acre of nearly all crops was below normal. In the San Joaquin Valley the raisin crop was 20,000 tons less than that of 1919. The hay crop was everywhere short, pastures dried up earlier than usual, and in regions where alfalfa is grown without irrigation the water table dropped so low that the crop was markedly deficient in quantity and in quality. As orchards were given preference in the distribution of irrigation water, the fruit crop was large. In fact, because of increased acreage of bearing orchards the shipments in 1920 were larger than those of 1919. Up to October 12 a total of 26,504 carloads of deciduous fruit were shipped from the State, compared with 23,249 carloads during the same period in the previous year.

WATER SHORTAGE AND RICE GROWING.

From an agricultural viewpoint, the rice growers were affected more by the water shortage than any other single group. Rice growing is a new industry in California, the first experiments on a commercial scale having been inaugurated in 1914. The rich alluvial flood plain of the Sacramento River has been found to be well adapted for rice growing, and the weather of the region is ideal. The growing of rice has been the means of transforming worthless swamp land into land worth several hundreds of dollars per acre. The rice crop of 1920 is valued at $62,000,000.

The old crops of the Sacramento Valley—grain, alfalfa, and fruit—use each season about 18 inches of water, enough to cover the soil to that depth is all applied at once. Rice, on the other hand, requires 60 to 120 inches of water instead of 18 inches. Moreover, it is estimated that 40 inches of water evaporate off of a rice field during the hot, dry summer. The fields are flooded artificially during the growing season and drained just before harvest. Abundant water is needed each summer until about September 15.

In anticipation of the impending water shortage the rice growers voluntarily reduced by 50,000 acres the area devoted to rice in 1920 as compared with that used in 1919. The watermaster appointed by the conference devoted practically all of his efforts to conserve and to reduce the water demands of the rice growers. President William Durbrow, of the Glen-Colusa Irrigation District, stated in the Pacific Rural Press of August 28, 1920, that "the Sacramento River has been practically pumped dry."

The landowners in the delta region and the commercial interests of the San Francisco Bay region united forces in the spring of 1920 and sought an injunction in the courts of law for the purpose of restraining the rice growers of the Sacramento Valley from taking water from the Sacramento River. They reasoned that the damages they had sustained and were about to sustain were due to the encroachment of saline water of the bay because of the decreased flow of fresh water of the Sacramento River, and that this diminished flow was due to the excessive pumping of water for rice irrigation upstream. The rice growers contended that the decreased flow was the natural result of the deficient precipitation of the past four rainy seasons, which had depleted the mountain reservoirs and lowered the ground water level to abnormally low stands. Suit was brought in the name of the town of Antioch, which contends that its domestic water supply is ruined. The case involved $62,000,000, the value of the rice crop, the largest amount ever involved in litigation in the State of California.

As is usual in law cases, the suit filed last spring has been long delayed in settlement, and the case is still before the courts, though the rice crop is now being harvested. However, much depends upon the outcome of the case, as it is believed that this is a forerunner of a more important suit which will take years to decide and which will involve many questions. It is sufficient to say that the problem of water rights is a complex one in California. Unfortunately, the law is not clear, and riparian and priority rights are so involved that a layman can not comprehend them. It appears that additional legislation will be needed to clear up many doubtful points at issue.

MISCELLANEOUS RESULTS OF WATER SHORTAGE.

Hydroelectricity is the principal source of mechanical power in California. The natural flow of streams is the ultimate source of power in the winter and spring months and water from storage reservoirs turns the wheels in the summer. Supplementary steam plants burning fuel oil are used in the autumn and at other times when hydroelectricity is unavailable.

Because the natural flow of streams was abnormally low and the stored water was deficient, resort to steam

plants for generating electricity throughout central and northern California was general during 1920. Because of the high price of fuel oil, and the increased cost of transportation and higher labor charges, the public utility commission granted the power companies permission to raise rates on electricity 15 per cent. This served as an excuse for higher rents, and all residents thus felt another increase in the cost of living, indirectly due to the deficient precipitation of last winter. The street car companies, the largest single users of electricity, adopted the skip-stop system to reduce consumption of energy, and also took off many cars to reduce the demand for power. Through moral suasion and a simple presentation of the facts, the utility commission's power administrator succeeded in eliminating all electric advertising signs on five nights of the week, and the unnecessary lighting of store windows and streets was reduced. In the mountain regions many mines using electric power were compelled to shut down. Gold dredgers using electricity ceased to operate.

In the Santa Clara Valley the well situation became serious in midsummer, owing to the depletion of underground waters. Emergency measures were adopted to preserve the levels of these underground waters so that the overlying orchards could be saved.

At the United States Immigration Station on Angel Island, in San Francisco Bay, the only well on the island went dry in midsummer, and fresh water had to be transported by barge from Marin County.

Due to the deficient precipitation of the past four rainy seasons, the forests in the elevated regions of California became very dry and suffered severe injury from fire during the summer. August, 1920, was perhaps the most disastrous month for forest fires which the State has thus far experienced. The situation became so serious that billboard posters were displayed by the United States Forest Service, informing citizens of the situation and cautioning those going to the forests for recreation to be particularly careful in the use of fire. Experienced fire-fighters were transported by aeroplane to the larger conflagrations. Lightning was a prolific source of fires in the parched forests throughout the long dry summer. The "back fire" from an automobile truck passing near Paradise, Butte County, set fire to a dry pasture, and 15,000 acres were burned over before the fire was controlled.

Relief came as a result of copious showers and cool weather in October. Fruit trees were revived, the forest-fire hazard was reduced, and the hydroelectric situation was relieved to such an extent that all power restrictions were immediately removed. Thus ended a season in which more attention was paid to rainfall statistics than ever before in the history of California. It is no exaggeration to say that for the past year the official rainfall data have occupied a place in public interest on a par with vital statistics, bank clearings, stock quotations, and market reports.

In commenting on the situation, the San Francisco Chronicle in an editorial on August 13 stated:

> Rain or shine, for the next decade the most important matter before our people will be the storage, so far as humanly possible, of every drop of water which falls on the State, and its utilization for irrigation and the development of power.

THE RELATION OF PROLONGED TROPICAL DROUGHTS TO SUN SPOTS.

By Prof. W. H. Pickering.

[Mandeville, Jamaica, July 2, 1920.]

SYNOPSIS.

A study of the collected rainfall data covering the last 50 years in the island of Jamaica has shown that there have been 12 droughts, 9 of which have followed closely after a sun-spot maximum or minimum. It appears that droughts occurring after the maxima show a greater deficiency of rainfall, and last longer, than those occurring after the minima. On the basis of sun-spot data a drought, predicted in March, 1919, to begin during 1919 or 1920, actually began in June, 1919, and was continuing at the time of writing the paper. It is suggested that the cause of the variations of rainfall may lie in the effect of changes in ocean temperatures on condensation and evaporation in the Tropics, and the increased solar magnetic activity after sun-spot maxima, although the reason for such a solar relation is not apparent. The effects of volcanic dust on radiation may also be a factor.—*C. L. M.*

The island of Jamaica is situated south of Cuba, in latitude 18° N. Its area is 4,200 square miles, or a trifle less than that of the State of Connecticut. The whole island is mountainous, culminating in the east in Blue Mountain Peak, 7,360 feet in height, but in the greater part of the island the elevations do not exceed 2,000 to 3,000 feet. At the suggestion and under the superintendence of the late Maxwell Hall, the Government, in 1870, began publishing the rainfall data for the island, and the fiftieth year has just been completed.

The rain is collected in gauges 5 inches in diameter with their tops elevated 1 foot above the ground. The observers are Government officials, planters, and cattlemen. In 1870 there were 24 stations, one of them dating back to 1862. Less than a dozen of these original stations are still maintained, others taking their place. On January 1, 1920, there were 196 stations, or one for every 22 square miles of territory, scattered as uniformly as practicable over the island. At no station here considered have the observations been continued for less than 10 years.

The rainfall is very unequal in different portions of the island. Thus at Moore Town near the entrance of a funnel-shaped valley at the extreme eastern end of the island, altitude 600 feet, where the trade winds impinge on the high mountains, the annual rainfall is 248 inches. On Blue Mountain Peak itself it is 175. On the other hand, at Bull Bay, 8 miles east of Kingston, and 20 miles from Moore Town, but on the other side of the mountains, it is only 33. The island has therefore been divided into four nearly equal sections according to their topographic features, and in Table 1 the rainfall is given for each of these sections and also for the island as a whole by decades. The mean rainfall for the island for the 50 years is 72.86 inches. It will be at once noticed that the means for the first two decades of this rainfall are very similar, and also the means for the last three, but that the two results differ from one another by about 10 inches. By examining the deviations from the mean, we see that the increased precipitation of recent decades is recorded mainly in the two rainiest sections of the island, the northeastern and west central, but that the other sections also show an appreciable increase. There does not seem to be any evidence that the change is due to the abandonment of certain stations and the establishment of others, but rather to an actual increase in the rainfall over the whole island.

In Table 2, in the second column, is given the mean annual rainfall for successive years, and in the third these results are smoothed by the well-known device of taking the mean of the first five results from the second column and entering it on the third line. The mean of the second, third, fourth, fifth, and sixth results is entered on the fourth line, and so on. These results are plotted in

figure 1 and show clearly the gradual increase of rainfall. Owing to the drought of the present year, the next point to be entered will be appreciably lower than the last. If we have now reached a maximum, and the results are periodic, the semiperiod is 44 or 35 years. According to the Brückner whole period of 35 years, the interval from 1871 to 1885, inclusive, should be wet and the following interval dry. This does not seem to be borne out by the facts.

In Table 3 is given the rainfall by months. Two means are taken, one for the two earlier dry decades and the other for the three later wet ones. It will be noted that the rainfall in January, May, August, and December has not materially altered, but that in April and in each of the three autumn months the increase exceeds an inch, the late autumn rain thus becoming much more marked than formerly. In Table 4 is given the rainfall by months and the deviation from the means as found in Table 3. The last columns give the duration and maximum deficiency of every prolonged drought that lasted at least 10 months and exceeded 12 inches. The two most severe droughts not entered in the table occurred in 1882 and in 1918. The first of these showed a deficiency of 11 inches and lasted 9 months. The deficiency of the

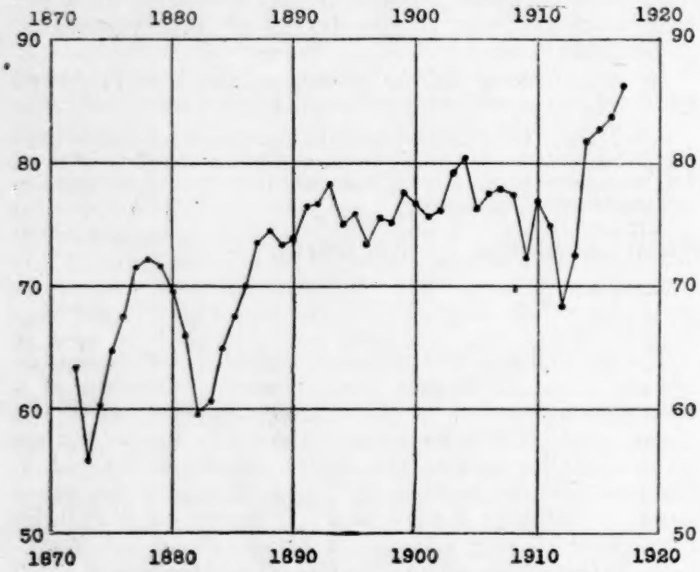


FIG. 1.—Smoothed graph of the rainfall in Jamaica, 1870-1920.

other amounted to 13 inches, but its duration was only 7 months. Numerous less marked droughts also occur, increasing in numbers as the required conditions are made less and less severe.

In the first two columns of Table 5 the dates of the droughts are expressed in years and tenths and the deficiency in inches, the decimal being omitted. The third column gives the duration in months, and the fourth the dates of the sun-spot maxima and minima since 1870, the latter being printed in italics. The first six of these dates are taken from Miss Clerke's *History of Astronomy*, fourth edition, 462. For the last three I am indebted to Prof. Adams, the eighth being Wolfer's revised value, and the last the result obtained at Mount Wilson. The fifth column gives the differences between the numbers in the first and fourth. It will be noted that every sun-spot maximum and minimum has been followed by a drought, and that three other droughts have also occurred, 12 in all. The last numbers in the second and hird columns are followed by a +, since the present drought is not yet over.

In Table 6 the first four columns indicate that the average of these differences for the four maxima, taken from the fifth column of Table 5, is 2.3 ± 0.5 years, and the average for the four minima is 1.4 ± 0.3 years. These differences may, for convenience of predicting future droughts, be expressed as two years four months, and one year five months. The 12 droughts have occurred on the average at intervals of 4.17 years. If their relation to the sun spots was due merely to chance, the average deviation should be one-fourth of this, or 1.04 years. Not one of the deviations in Table 6 reaches this figure. From this we conclude, considering the inevitable errors occurring in fixing the exact dates of the sun-spot maxima and minima, that a real relation subsists between these dates and those of the Jamaica droughts.

The fifth and sixth columns show that the average deficiency at a sun-spot maximum is 32 inches, and at a minimum 20. The next two columns show that the average durations are 20 and 13 months, respectively, and the last two, obtained by dividing the deficiency by the duration, that the average intensities are 1.7 and 1.5 inches per month. It therefore appears that the droughts occurring after the maxima not only show a greater deficiency, but also last longer and are more intense than those occurring after the minima.

The three droughts not associated with the sun spots had an average deficiency of 23 inches, a duration of 14 months, and an intensity of 1.6. They were therefore very slightly more severe than those occurring after the minima. From this we conclude that while the condition of the solar surface is an index to the majority of the prolonged Jamaica droughts, there is some other less important cause also at work, occasionally producing a similar result. [See discussion by W. J. H., below.] If we were willing to include a very minor drought, whose maximum occurred in April, 1888, whose deficiency was 9.48 inches, and its duration 5 months, we might consider these droughts, too, to be periodical. The intervals between them last, respectively, for 12.5, 11.3, and 13.1 years; mean 12.3.

It may be noted in passing that on the strength of a preliminary investigation published in the Annals of Harvard College Observatory, **82**:16, and on the sun-spot data communicated to the writer by Prof. Adams, a drought was predicted for Jamaica to occur during the year 1919 or 1920. This prediction was published in the local island paper in March, 1919. The drought actually began, as shown in Table 4, in June, 1919, and has not ended as yet. Deficiency so far 22.84 inches, Table 4. By the more accurate data here given the beginning would have been set for the summer of 1919, and the end for the autumn of 1920, with a maximum deficiency of about 30 inches. If the mean could be relied on, the drought would last through November. It may be added that the drought has extended throughout the whole of the West Indies, from Cuba to British Guiana, and in places has caused considerable suffering from the failure of crops, and a deficiency in the sugar output.

As to its cause, it may be stated that the deficiency of rainfall appears to be due mainly to a deficiency in the spring and autumn months, which bring us most of our rain. During the last three droughts the lack of rain has been associated with a lack of heavy afternoon cloud, our rainfall occurring chiefly in the afternoon. It therefore appears probable that the droughts are due mainly to a lack of density in the tropical belt of cloud which follows the sun north and south in its yearly course through the heavens. Why the density of this cloudy belt should vary with the sun spots is not very clear, but it may be noted that the maximum intensity of the solar magnetic storms, and the greatest rate of change in the solar activity, is said to occur about two years

after the sun-spot maxima. (Journal British Astronomical Association, 1920, **30**: 186.) It would seem that since there is no appreciable change in the insolation, that a change in the rate of solar activity after the maxima and again after the minima would be more likely to affect terrestrial evaporation and condensation than the mere spottedness of the sun's surface.

In closing it should be stated that the first suggestion of the relation between the Jamaica rainfall and the semiperiod of the sun spots is to be found in Maxwell Hall's Rainfall of Jamaica, second edition, 1911. Sir Norman and Dr. W. J. S. Lockyer had previously found a similar relation in the rainfall of India. It should also be mentioned that the writer has received much assistance in the collection of the more recent data, as well as in the correction of certain typographical errors in that which had been already published, from the island's Associate Meteorologist, Miss C. Maxwell Hall.

Table 1.—*Rainfall by sections, in inches.*

Decade.	N. E.	Dev.	N.	Dev.	W. C.	Dev.	S.	Dev.	Island.	Dev.
1870-1879	91.04	−4.88	57.34	+0.68	70.73	−12.84	50.53	−4.76	67.41	−5.45
1880-1889	84.96	−10.96	50.96	−5.70	75.74	−7.83	54.51	−0.78	66.54	−6.32
1890-1899	98.60	+2.68	57.36	+0.70	92.17	+8.60	56.45	+1.16	76.15	+3.29
1900-1909	99.48	+3.56	57.37	+0.71	89.21	+5.64	61.90	+6.61	76.98	+4.12
1910-1919	105.50	+9.58	60.28	+3.62	90.01	+6.44	53.07	−2.22	77.21	+4.35
Average	95.92	±6.33	56.66	±2.28	83.57	±8.27	55.29	±3.10	72.86	±4.70

Table 2.—*Annual rainfall.*

Year.	Rain.	Smoothed.	Year.	Rain.	Smoothed.	Year.	Rain.	Smoothed.
1870	89.43	......	1887	70.66	73.48	1904	88.15	80.36
1871	50.09		1888	72.11	74.39	1905	85.20	76.21
1872	45.18	63.34	1889	74.15	73.20	1906	86.71	77.46
1873	63.06	55.94	1890	64.42	73.88	1907	52.61	77.86
1874	68.94	60.19	1891	84.70	76.55	1908	74.62	77.37
1875	52.42	64.85	1892	73.00	76.80	1909	90.17	73.21
1876	71.35	67.52	1893	86.49	78.24	1910	82.76	76.94
1877	68.49	71.50	1894	75.39	75.02	1911	60.90	74.88
1878	76.42	72.10	1895	71.62	75.94	1912	76.26	68.32
1879	88.84	71.56	1896	68.61	73.40	1913	64.34	72.76
1880	55.44	69.43	1897	77.59	75.50	1914	57.36	81.84
1881	68.60	66.00	1898	73.82	75.10	1915	104.95	82.78
1882	57.87	59.61	1899	85.82	77.57	1916	106.32	83.70
1883	59.26	60.50	1900	69.65	76.72	1917	80.93	86.11
1884	56.90	64.90	1901	80.96	75.64	1918	68.92	......
1885	59.86	67.46	1902	73.37	76.10	1919	69.45	......
1886	90.61	70.03	1903	68.38	79.21			

Table 3.—*Mean rainfall by months, in inches.*

Decade.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1870-1879	4.46	2.38	3.34	3.25	9.05	4.74	4.31	6.66	6.85	10.07	6.71	5.59
1880-1889	3.78	2.51	2.49	4.18	9.07	7.77	4.32	6.83	6.87	8.04	5.08	5.60
Average	4.12	2.44	2.92	3.72	9.06	6.26	4.32	6.74	6.86	9.06	5.89	5.59
1890-1899	3.13	2.97	2.75	5.17	10.56	5.81	5.64	6.35	7.64	13.01	7.71	5.41
1900-1909	4.27	3.30	3.96	4.59	7.93	9.73	4.76	6.84	8.28	10.15	8.09	5.08
1910-1919	4.04	2.75	3.54	6.03	9.12	5.61	4.70	7.42	8.26	9.51	10.60	5.61
Average	3.81	3.01	3.42	5.26	9.20	7.05	5.03	6.87	8.06	10.89	8.80	5.37

Table 4.—*Rainfall by months.*

Year.	January.		February.		March.		April.		May.		June.		July.		August.		September.		October.		November.		December.		Droughts.	
	Rain.	Variation.	Rain.	Variation.	Rain.	Variation.	Rain.	Variation.	Rain.	Variation.	Rain.	Variation.	Rain.	Variation.	Rain.	Variation.	Rain.	Variation.	Rain.	Variation.	Rain.	Variation.	Rain.	Variation.	Duration.	Deficiency (inches).
1870	3.99	−0.13	4.35	+1.91	3.10	+0.18	2.79	−0.93	17.38	+8.32	3.58	−2.68	4.38	+0.01	5.72	−1.02	8.05	+1.19	16.74	+7.68	12.50	+6.61	6.90	+1.31	......	
1871	2.40	−1.72	1.60	−0.84	2.29	−0.63	3.46	−0.26	6.43	−2.63	1.98	−4.28	3.79	−0.53	3.46	−3.28	5.70	−1.16	8.88	−0.18	5.88	−0.01	4.22	−1.37	Jan.-	38.69
1872	3.00	−1.12	2.84	+0.40	3.06	+0.14	2.06	−1.66	5.18	−3.88	2.41	−3.85	2.89	−1.43	5.24	−1.50	4.55	−2.31	6.09	−2.97	3.13	−2.76	4.73	−0.86	Dec.	
1873	8.15	+4.03	1.94	−0.50	5.47	+2.55	1.15	−2.57	5.06	−4.00	2.58	−3.68	2.56	−1.76	7.51	+0.77	10.73	+3.87	8.57	−0.49	3.53	−2.36	5.81	+0.22	......	
1874	3.44	−0.68	2.20	−0.24	0.61	−2.31	4.40	+0.68	10.65	+1.59	3.96	−2.30	2.57	−1.81	9.65	+2.91	6.82	−0.04	11.69	+2.63	10.52	+4.63	2.49	−3.10	Dec.-	18.81
1875	2.57	−1.55	0.67	−1.77	2.59	−0.33	3.05	−0.67	8.54	−0.52	3.74	−2.52	3.87	−0.45	5.13	−1.61	7.60	+0.74	5.58	−3.48	2.34	−3.55	6.74	+1.15	Nov.	
1876	6.00	+1.88	0.96	−1.48	1.63	−1.29	4.68	+0.96	8.04	−1.02	5.40	−0.86	8.15	+3.83	5.06	−1.68	5.19	−1.67	11.36	+2.30	8.96	+3.07	5.72	+0.13	......	
1877	5.94	+1.82	1.18	−1.26	5.38	+2.46	2.91	−0.81	15.03	+5.97	6.50	+0.24	4.68	+0.36	1.76	−4.98	5.01	−1.85	4.50	−4.56	7.63	+1.74	7.88	+2.29	......	
1878	6.35	+2.23	2.80	+0.36	2.78	−0.14	0.70	−3.02	4.86	−4.20	6.63	+0.37	5.85	+1.53	10.80	+4.06	7.43	+0.57	11.29	+2.33	7.32	+1.43	9.61	+4.02	......	
1879	2.81	−1.31	5.30	+2.86	6.49	+3.57	7.28	+3.56	9.14	+0.08	10.64	+4.38	4.47	+0.15	12.32	+5.58	7.38	+0.52	15.96	+6.90	5.29	−0.60	1.76	−3.83	Nov.-	17.32
1880	4.36	+0.24	0.96	−1.48	1.10	−0.82	2.77	−0.95	11.60	+2.54	3.09	−3.17	3.86	−0.46	9.58	+2.84	3.97	−2.89	4.00	−5.06	2.21	−3.68	7.94	+2.35	Nov.	
1881	1.22	−2.90	4.01	+1.57	1.30	−0.42	4.63	+0.91	10.28	+1.22	5.56	−0.70	4.77	+0.45	6.21	−0.53	7.68	+0.82	12.08	+3.02	7.52	+1.63	3.34	−2.25	......	
1882	2.92	−1.20	1.93	−0.51	3.54	+0.62	3.32	−0.40	8.22	−0.84	2.33	−3.93	3.76	−0.56	4.80	−1.94	8.78	+1.92	8.96	−0.10	5.36	−0.53	3.95	−1.64	......	
1883	5.49	+1.37	3.50	+1.06	4.08	+1.16	3.34	−0.38	5.29	−3.77	4.98	−1.28	3.15	−1.17	5.42	−1.32	7.82	+0.96	8.15	−0.91	5.12	−0.77	2.92	−2.67	......	
1884	4.72	+0.60	3.44	+1.00	2.57	−0.41	1.85	−1.87	6.72	−2.34	6.89	+0.63	2.52	−1.80	5.06	−1.68	6.23	−0.63	9.52	+0.46	5.00	−0.89	2.44	−3.15	Apr.-	38.59
1885	1.73	−2.39	1.49	−0.95	1.47	−1.45	4.73	+1.01	4.90	−4.16	3.32	−2.94	3.01	−1.29	6.19	−0.55	6.22	−0.64	6.37	−2.69	4.74	−1.15	15.69	+10.10	Nov.	
1886	5.32	+1.11	4.56	+2.21	2.68	−0.24	6.39	+2.67	5.30	−3.76	23.36	+17.10	6.22	+1.90	13.54	+6.80	5.90	−0.96	7.98	−1.08	3.70	−2.19	5.66	+0.07	......	
1887	6.02	+1.90	2.32	−0.12	2.38	−0.54	4.47	+0.75	9.32	+0.26	8.89	+2.63	7.19	+2.87	6.91	+0.17	5.77	−1.09	8.47	−0.59	8.17	+2.28	0.75	−4.84	......	
1888	1.36	−2.76	1.89	−0.55	1.70	−1.22	3.61	−0.11	21.24	+12.18	6.77	+0.51	2.65	−1.67	5.47	−1.27	8.10	+1.24	4.38	−4.68	4.59	−1.30	10.35	+4.76	......	
1889	4.78	+0.66	0.90	−1.54	4.19	+1.27	6.71	+2.99	7.82	−1.24	12.52	+6.26	6.08	+1.76	5.12	−1.62	8.20	+1.34	10.49	+1.43	4.37	−1.52	2.97	−2.62	......	
1890	5.21	+1.40	2.92	−0.09	5.84	+2.42	3.37	−1.89	5.57	−3.63	4.13	−2.92	4.99	−0.04	6.92	+0.05	6.52	−1.54	7.04	−3.75	6.52	−2.28	5.39	+0.02	Apr.-	19.69
1891	3.45	−0.36	2.24	−0.77	0.84	−2.58	8.49	+3.23	12.28	+3.08	9.91	+2.86	5.57	+0.54	7.45	+0.58	6.35	−1.71	15.32	+4.43	7.65	−1.15	5.15	−0.22	Mar.	
1892	4.00	+0.19	1.38	−1.63	2.27	−0.55	2.82	−2.44	8.53	−0.67	7.31	+0.26	4.44	−0.59	7.65	+0.78	8.86	+0.80	12.17	+1.28	9.96	+1.16	3.61	−1.75	......	
1893	3.44	−0.37	3.24	+0.23	1.92	−1.50	5.42	+0.16	10.90	+1.70	7.20	+0.15	9.15	+4.12	6.72	−0.15	7.92	−0.14	10.30	−0.59	10.10	+1.30	10.81	+5.44	......	
1894	2.05	−1.76	2.52	−0.49	3.33	−0.09	5.84	+0.58	16.64	+7.44	3.90	−3.15	5.92	+0.89	4.20	−2.77	6.98	−1.08	12.40	+1.51	5.05	−3.75	6.56	+1.19	......	
1895	1.31	−2.50	5.00	+1.99	2.18	−1.24	6.11	+0.85	9.90	+0.70	3.66	−3.39	4.99	−0.04	8.11	+1.24	6.87	−1.19	11.98	+1.09	7.72	−1.08	3.79	−1.58	......	
1896	5.25	+1.44	4.86	+1.85	4.28	+0.86	3.67	−1.59	9.96	+0.76	4.84	−2.21	5.03	0.00	4.74	−2.13	8.24	+0.18	7.57	−3.38	4.57	−4.23	5.66	+0.29	June-	18.25
1897	0.88	−2.93	0.77	−2.24	1.82	−1.60	7.06	+1.80	10.91	+1.71	4.92	−2.13	5.92	+0.89	6.55	−0.32	10.13	+2.07	19.26	+8.37	5.73	−3.07	3.64	−1.73	Mar.	
1898	1.75	−2.06	3.93	+0.92	1.26	−2.16	4.09	−1.17	16.76	+7.56	7.60	+0.55	6.50	+1.47	6.92	+0.05	7.10	−1.96	10.38	− 051	4..78	−4.02	2.75	−2.62	Sept.-	21.08
1899	3.96	+0.15	2.84	−0.17	3.76	+0.34	4.80	−0.46	4.20	−5.00	4.66	−2.39	3.86	−1.17	4.22	−2.65	7.44	−0.62	23.72	+12.84	14.99	+6.19	7.37	+2.00	Sept.	
1900	5.20	+1.39	4.15	+1.14	2.42	−1.00	5.67	+0.41	7.77	−1.43	6.16	−0.89	7.18	+2.15	5.38	−1.49	8.12	+0.06	6.50	−4.39	5.22	−3.58	5.88	+0.51	......	
1901	3.91	+0.10	1.17	−1.84	3.32	−0.10	2.57	−2.69	6.13	−3.07	14.03	+6.98	7.59	+2.46	6.49	−0.38	10.60	+2.54	9.76	−1.13	10.02	+1.22	5.37	0.00	......	
1902	5.68	+1.87	3.06	+0.05	4.24	+0.82	5.40	+0.14	8.97	−0.23	10.28	+3.13	3.44	−1.59	5.39	−1.48	5.89	−2.17	7.19	−3.70	5.60	−3.20	8.23	+2.86	July-	13.25
1903	1.94	−1.87	1.40	−1.61	3.19	−0.23	4.90	−0.36	10.63	+1.43	6.00	−1.05	4.30	−0.73	12.79	+5.92	5.34	−2.72	7.28	−3.61	5.78	−3.02	4.83	−0.54	Apr.	
1904	3.42	−0.39	4.66	+1.65	6.84	+3.42	5.91	+0.65	7.57	−1.69	15.20	+8.15	4.26	−0.77	5.47	−1.40	6.49	−1.57	16.58	+6.31	7.87	−0.93	3.94	−1.43	......	
1905	7.83	+4.02	2.99	−0.02	7.48	+4.06	5.14	−0.12	8.20	−1.00	10.10	+3.05	2.73	−2.30	6.17	−0.70	8.27	+0.21	12.36	+1.47	6.77	−2.03	7.17	+1.80	......	
1906	3.37	−0.44	5.15	+2.14	5.50	+2.08	8.02	+2.76	13.23	+4.03	11.47	+4.42	4.19	−0.84	6.98	+0.11	10.70	+2.64	8.44	−2.45	7.60	−1.20	2.06	−3.31	Oct.-	31.12
1907	2.58	−1.23	3.75	+0.74	0.36	−3.06	1.24	−4.02	5.12	−4.08	5.96	−1.09	4.26	−0.77	4.63	−2.24	5.39	−2.67	10.51	−0.38	4.26	−4.54	4.55	−0.82	Dec.	
1908	4.38	+0.57	5.05	+2.04	3.42	0.00	3.45	−1.81	4.92	−4.28	11.65	+4.60	4.17	−0.86	7.00	+0.13	6.00	−2.06	11.05	+0.16	6.52	−2.28	7.01	+1.61	......	
1909	4.35	+0.54	1.63	−1.38	2.87	−0.55	3.64	−1.62	6.84	−2.36	6.42	−0.63	5.52	+0.49	8.14	+1.27	15.96	+7.90	11.85	+0.96	21.22	+12.42	1.73	−3.64	......	
1910	5.29	+1.48	2.20	−0.81	4.45	+1.03	3.56	−1.70	5.23	−3.97	5.74	−1.31	5.57	+0.54	7.52	+0.65	8.71	+0.65	14.74	+3.85	7.61	−1.19	12.14	+6.77	......	
1911	4.35	+0.54	1.44	−2.37	2.02	−1.40	4.00	−1.26	10.31	+1.11	3.81	−3.24	3.22	−1.81	4.37	−2.50	5.71	−2.35	8.28	−2.61	4.92	−3.88	8.46	+3.09	June-	23.88
1912	4.40	+0.59	2.34	−0.67	4.88	+1.46	2.21	−3.05	4.60	−1.60	2.43	−4.62	4.30	−0.73	6.38	−0.49	6.23	−1.83	8.25	−2.64	26.74	+17.94	3.50	−1.87	Oct.	
1913	3.64	−0.17	1.14	−1.87	3.79	+0.37	7.94	+2.68	8.06	−1.14	3.80	−3.25	4.48	−0.55	5.50	−1.37	6.90	−1.16	7.02	−3.87	8.65	−0.15	3.42	−1.95	May-	31.30
1914	2.65	−1.16	2.06	−0.95	4.10	+0.68	4.74	−0.52	6.62	−2.58	5.24	−1.81	2.94	−2.09	4.22	−2.65	3.76	−4.30	6.33	−4.56	9.74	+0.94	4.96	−0.41	Oct.	
1915	6.32	+2.51	2.90	−0.11	3.23	−0.19	8.77	+3.51	6.44	−2.76	11.90	+4.85	5.82	+0.79	14.10	+7.23	16.68	+8.62	10.73	−0.16	11.01	+2.21	6.05	+0.68	......	
1916	3.57	−0.30	5.24	+2.23	2.73	−0.69	8.19	+3.92	15.55	+6.35	6.33	−0.72	7.56	+2.53	13.84	+6.97	7.62	−0.44	16.26	+5.37	17.80	+9.00	1.60	−3.77	......	
1917	3.08	−0.73	3.27	+0.26	2.50	−0.92	7.07	+1.81	7.35	−1.85	8.32	+1.27	5.21	+0.18	7.52	+0.65	15.43	+7.37	6.84	−4.05	9.40	+0.60	4.94	−0.43	......	
1918	0.88	−2.93	3.38	+0.37	5.82	+2.40	6.38	+1.08	12.56	+3.36	5.06	−1.99	3.60	−1.43	7.26	+0.39	5.41	−2.65	8.94	−1.95	5.03	−3.77	4.60	−0.77	......	
1919	6.29	+2.48	2.50	−0.51	1.92	−1.50	7.44	+2.18	14.57	+5.31	3.46	−3.59	4.33	−0.70	3.54	−3.33	6.20	−1.84	7.69	−3.20	5.11	−3.69	6.46	+1.09	June-	22.84
1920	2.82	−0.99	2.40	−0.61	3.41	−0.01	0.29	−4.97	8.20	−1.00	......	......	......	......	......	......	......	......	......	......	......	......	......	......	May.	

TABLE 5.—*Droughts and sun spots.*

Droughts.	Inches.	Duration.	Sun.	D-S.
1873.0	39	24	1870.6	+2.4
1875.9	19	12	....	....
1880.9	17	13	*1878.9*	+2.0
1885.9	39	32	1884.0	+1.9
1891.2	20	12	*1890.2*	+1.0
1897.2	18	10	1894.0	+3.2
1899.7	21	13	....	....
1903.3	13	10	*1901.9*	+1.4
1908.0	31	15	1906.4	+1.6
1912.8	30	17	....	....
1914.8	31	18	*1913.6*	+1.2
1920	22+	12+	1918.6	....

TABLE 6.

Interval.				Deficiency.		Duration.		Intensity.	
Max.	Dev.	Min.	Dev.	Max.	Min.	Max.	Min.	Max.	Min.
2.4	+0.1	2.0	+0.6	39	17	24	13	1.6	1.3
1.9	−0.4	1.0	−0.4	39	20	32	12	1.2	1.7
3.2	+0.9	1.4	0.0	18	13	10	10	1.8	1.3
1.6	−0.7	1.2	−0.2	31	31	15	18	2.1	1.7
2.3	±0.5	1.4	±0.3	32	20	20	13	1.7	1.5

DISCUSSION.

I notice that the drought around 1873 coincides with world-wide low temperatures, probably of volcanic origin: that the drought around 1883 agrees with the cold period at the time of the Krakatoa eruption; and that the drought around 1912 was at the time of the Katmai eruption.—*W. J. Humphreys.*

The explanation for these droughts which occurs to me is as follows: (1) That on account of probable subnormal ocean-surface temperatures to windward the moisture content of the air passing over Jamaica is reduced, and therefore convectional currents of normal strength must produce less rainfall than usual; (2) that water colder than usual in this region would not only reduce the moisture content of the air, but also, by keeping the air cooler, would reduce the usual intensity of development of the low pressures that mark this region in the warmer half year, and, therefore, prevent the attainment of the usual strength of the convectional currents. The combination of reduced moisture and reduced convection would favor the occurrence of droughts. The fact that the droughts are general would indicate the operation of some such generally effective cause.

It has been found that a reduced temperature of the equatorial current (as indicated in the temperature of the Gulf Stream) follows after a month or months with unusually strong trade winds. Such winds tend to concentrate the warm surface layers to windward, which are replaced by cooler water from below and from higher latitudes. The reduction in water-surface temperatures about the West Indies seems to reach its maximum five months to a year after the occurrence of unusually strong trades in the eastern Atlantic.[1]

How can this be connected with sun spots? Prof. Pickering shows that the worst droughts come just after sun-spot maxima. It is generally conceded that the general circulation of the atmosphere is intensified by the greater amount of heat which probably enters the atmosphere at times of sun-spot maxima. Therefore, the trades, sharing in this general intensification, would produce first a plus and then a minus departure in water-surface temperature, as explained above, and in the course of 6 to 10 months the drought effects would become noticeable first in northeastern Brazil and then in the West Indies. Since the maximum intensity of the general circulation would necessarily lag after the maximum of sun spots, the total delay in the occurrence of the worst drought conditions may be easily accounted for in this way.—*Charles F. Brooks.*

In a letter of September 7, 1920, Prof. Pickering asks whether the cold-water speculations presented above would account for the droughts in California and Australia.

Discussing why the dates of the end of the droughts were chosen rather than the beginning, Prof. Pickering adds the following to what he presented in his paper:

> The end of a drought is the time of the maximum deficiency of water; it is a perfectly definite date and is what particularly interests agriculturists. Different persons might select different dates for the beginning. I do not believe that the sun spots themselves, or their absence, cause the droughts. The spots are merely a surface indication of an overturn of material and temperature occurring beneath the solar surface in connection with magnetic storms. The accumulation of these conditions reaches its greatest rate of change at about the time of the end of the drought. This is indicated by the recorded magnetic variations. What the precise logical connection may be between the droughts and the magnetic disturbances I do not pretend to know, but the sun spots come first, and enable the prediction to be made. I have only to derive statistics from observed rainfall data to show the coincidence.

[1] See MO. WEATHER REVIEW November 1918, 46:510-512.

AN APPROXIMATE SEVEN-YEAR PERIOD IN TERRESTRIAL WEATHER, WITH SOLAR CORRELATION.[1]

By H. W. CLOUGH.

[Weather Bureau, Washington, D. C., Dec. 3, 1920.]

SYNOPSIS.

Investigators of the relation between terrestrial weather and solar activity have generally agreed that high temperature is associated with a minimum of sun spots in the 11-year period, and vice versa. This relation is most clearly defined in the Tropics, but with increase of latitude the amplitude decreases, and there is a tendency to the formation of a secondary crest, which approaches in amplitude that of the primary crest.

A seven or eight year period has been independently noted by many investigators in the variations of temperature, pressure, and precipitation.

The author presents data and curves for the United States showing the persistence of a period in weather averaging 7 years from 1790 to 1919. The length of this period varies systematically and periodically over an extreme range of 4 or 5 years in a cycle of about 25 to 30 years. These variations synchronize closely with similar variations in the length of the 11-year sun-spot period.

The combination of the 7-year and the 11-year periods results in the subordinate crests found in the curve of the 11-year variation in temperature, and probably accounts for the period averaging 21 or 22 years noted by many investigators.

THE 11-YEAR PERIOD.

Ever since the systematic observation of sun spots began in the early part of the seventeenth century, investigators have endeavored to discover some correlation between the variations of this feature of solar activity and the variations of terrestrial phenomena. Among the more prominent of these investigators may be mentioned Herschel (1801), Gautier (1844), Fritsch (1854), Köppen (1873), Nordmann (1903), Clough (1905), Newcomb (1908), Wallén (1910), Humphreys (1913), Mielke (1913), Köppen (1914), Meissner (1917), Helland-Hensen and Nansen[2] (1917). Köppen published in 1914 the most complete discussion of temperature variations, based on his own earlier paper of 1873, and two later papers—(1) the very extensive compilation by Mielke of data subsequent to 1870, and (2) the paper by Humphreys, calling attention to the depressions in the temperature curve resulting from volcanic dust veils. He concludes, with previous investigators, that the temperature curve varies inversely with the sun-spot curve, *i. e.*, high temperature occurs with a sun-spot minimum, and vice versa. In the Tropics the correlation is most regular and pronounced; the mean variation between the warmest year near sun-spot minimum and the coldest year near sun-spot maximum being about 0.50° C. In higher latitudes, however, the variation, while present, is of smaller amplitude and there is a tendency for the occurrence of a secondary crest in the colder temperate region. Helland-Hansen and Nansen express it as "a strongly marked tendency to a half sunspot period in the temperature variation." While, therefore, over the whole globe the primary maxima and minima occur near the corresponding minima and maxima of sun spots, in high latitudes the amplitude of the secondary variation approaches that of the primary variation.

The occurrence of a subordinate crest within the 11-year period has been noted in the variations of precipitation (Buchan, 1903, and Hellmann, 1909), height of water in lakes (Wallén, 1903), and the growth of trees (Douglass, 1919[3]).

Referring to his analysis of the Arizona pines for 500 years, Douglass says:

> The trees show a double-crested period of 11.4 years through nearly all the 500 years of the record. There are two well-developed maxima and minima, but they are rarely symmetrical. A 7-year period is also frequently observed.

A 7-YEAR PERIOD.

It is evident that while the 11-year period is that most prominently disclosed in the variations of terrestrial phenomena, a shorter variation exists which obscures or masks at times the 11-year period. Several writers have called attention to a seven or eight year period in temperature, pressure, and precipitation. Schott[4] found a 7-year period in the temperature variations of the interior of the United States from 1820 to 1870. This will be referred to below. In Signal Service Notes, No. XV, "Danger Lines and River Floods of 1882," appears the following statement regarding the stage of the Arkansas River at Fort Smith, Ark.:

> There would seem to be a cycle in the flow of the river of seven or eight years. High water, 1844, 1852, 1859, 1868, and 1878. Low water, 1847, 1856, 1863, 1871.

Bigelow in his barometry report,[5] referring to the secular variations of the pressure over the United States, says:

> The years of maximum pressure are 1874–75, 1882–83, 1890, 1896–97, the years of minimum pressure are 1878, 1884–85, 1893, having an interval of about eight years.

Maurer (Archives des Sci. Phys. Nat. Geneva, May, 1918) called attention to a well-marked periodicity of seven to eight years in the winter pressure in Central Europe, with maxima as follows: 1818–19, 1827–28, 1835–36, 1843–44, 1850–51, 1857–58, 1865–66, 1873–74, 1881–82, 1889–90, 1897–98, 1904–05, 1912–13.

Moore (Economic Cycles, N. Y., 1914) finds a 7- or 8-year period in rainfall and crop yield in the United States. References to a period of this length are occasionally met with in literature.

Schott employed well known statistical methods in his investigation of the secular variation in the temperature of the United States. By combining data from several adjacent stations to form an approximately homogeneous series and consolidating the results from several stations over a large area of the country, he obtained two type-curves, the first series comprising five stations in the North Atlantic States and the second series comprising five stations in the Mississippi Valley. The curves in his diagram represent data smoothed by the application of the process of successive means to the 4th order, eliminating the accidental and minor irregularities. Regarding these curves he says:

> The distinguishing features of these two type-curves appear well marked; the longer waves of the Atlantic stations show principal maxima in 1802, 1826, 1846, 1865, principal minima in 1785, 1816, 1836, 1857, the average interval being about 22 years. The shorter waves of the interior states show principal maxima in 1827, 1833, 1839, 1845, 1854, 1860, and principal minima in 1831, 1836, 1843, 1848, 1856, and 1867, the average interval being about 7 years. These undulations, however, are not sufficiently regular nor sufficiently distinct to serve as a basis for prediction; all that can be claimed for them is a general exponent of the character of the secular change.

[1] As in the case of any contribution, it is to be recognized that the Weather Bureau, while providing a medium for publication, does not thereby become officially responsible for the views presented.—*Editor.*

[2] Temperature variations in the North Atlantic Ocean and in the atmosphere. Smithsonian Misc. Colls., vol. 70, No. 4, 1920. (Translation.) (Abstract in MO. WEATHER REV., Apr., 1918, 46: 177–178.) This work contains a very comprehensive bibliography.

[3] A. E. Douglass: Climatic Cycles and Tree Growth. Carnegie Inst. of Wash. No. 289. 1919. (Includes bibliography.) (Presented in briefer form in *Ecology*, January, 1920, vol. 1, pp. 24–32.)

[4] Atmospheric temperature in the United States. Smithsonian Contrib. 277. Washington, 1876.

[5] Report of the Chief of the Weather Bureau, Vol. II, 1900–1901.

In the same diagram he gives the sunspot curve for comparison, regarding which he writes:

It is evident * * * that no intimate relation appears to exist between the two phenomena—they seem to have no features in common; the sun-spot period of about 11 years is not systematically followed by any of the temperature curves * * * and in general we have phases of the two curves presented in all possible combinations.

It will be made clear later that these conclusions by Schott do not essentially conflict with the conclusions reached by Köppen and others regarding the 11-year variation in temperature.

Thus independently various students have claimed a period of an average length of seven years in weather phenomena by a simple inspection of plotted data freed from minor irregularities by some smoothing process.

Enough has been stated to show the probable existence of this period and it will be the purpose of this paper to show that a period of about seven years has indeed characterized the weather of the United States since systematic observations began, about 1790, and, furthermore, to show that this period has varied systematically in length from four or five to nine or ten years.

METHODS EMPLOYED IN ESTABLISHING PERIODS.

Aside from the simple method of inspection of smoothed curves, many investigators have employed the methods of harmonic analysis, which presupposes that all the harmonic elements of a curve under analysis have fixed periods of invariable length. When this method is employed for the analysis of meteorological sequences, in which the elemental periods are believed to vary systematically in length, the results secured are likely to be illusory, especially if the changes in length and amplitude of the elements are considerable.

When by inspection or otherwise an approximate period has been identified as probably persisting over a long interval of time, its essential features may be exhibited by averaging together the like phases of several cycles.

Results thus secured are shown graphically by plotting in the usual manner. This is the method meteorologists have employed for many years in establishing hourly, daily, and other normals, as well illustrated in diurnal and annual variations where the periods are constant and well defined.

This is the method employed by Köppen, Turner, and others, and it has been ingeniously developed by Schuster in his well known device of the periodogram to disclose hidden periodicities.

Since, as previously stated, the sun-spot period itself and many meteorlogical sequences are of variable lengths of period, the results secured by the method mentioned must be interpreted with much caution.

VARYING LENGTH OF SOLAR AND METEOROLOGICAL PERIODS.

In 1905 I showed[a] that the sun-spot period of 11 years varied in length and that this variation was of a systematic nature. Newcomb (Astrophys. Jour., 1903) in a mathematical discussion of the Wolfer sun-spot epochs concluded that a uniform period existed and that the deviations were of an accidental nature, arising from imperfections of the records. I showed, on the contrary, that these deviations were systematic and periodic. The normal period is 11 years with phases subject to alternate acceleration and retardation during a cycle averaging 36 years. Thus, the Brückner meteorological cycle of 36 years has its counterpart in a solar cycle of 36 years; and, furthermore, it was shown that the minima of the Brückner cycle occur shortly after the occurrence of minima in the length of the 11-year sun-spot period. In addition, the Brückner cycle is not of uniform length but varies between 25 and 45 years, and these variations synchronize with similar variations in the length of the 36-year solar cycle. Evidence supporting this result is given by data extending over a period of 900 years.

All references to the 11-year period in weather have implied a uniform length of the period and the graphical representations of this variation by Köppen and others have been based on the hypothesis of a uniform period. Obviously, if the sun-spot period varies, as it actually does, the corresponding weather period must likewise vary. Admitting that the 36-year Brückner cycle varies systematically and periodically, as stated above, and if the 11-year weather period varies to correspond to its solar counterpart, then, inferentially, meteorological periods of shorter duration, which may be plausibly ascribed to a solar origin, should exhibit precisely analogous systematic variations.

THE SEVEN-YEAR VARIATION IN TEMPERATURE AND OTHER ELEMENTS.

Figure 1 presents curves of meteorological data smoothed to eliminate minor fluctuations. Curve 1 is Schott's Mississippi type-curve beginning with 1820. Curves 2, 3, and 4 show the individual curves for Cincinnati, Salem, and Philadelphia, serving to carry back these fluctuations to about 1790. The New Haven curve in Schott's diagram is practically identical with the Salem curve. The unsmoothed annual means of this station show clearly the short fluctuations between 1800 and 1820, shown faintly in the smoothed curves. Schott's curve ends in 1869. A smoothed curve for Lawrence, Kans., forms a continuation of the Fort Leavenworth data, a component of the Schott curve, and serves to bridge over the gap between the Schott data and the Signal Service data beginning in 1873.

Curve 5 is the smoothed mean maximum temperature for Dodge City, Kans. The Plains States between latitudes 35° and 45° show more clearly these 7-year fluctuations than any other section of the country. Sections farther north are in the main storm track, and at times, with the shifting of the storm track to the southward, experience a different régime of winds, hence their curves show more or less irregular minor fluctuations sufficiently to mask largely the regular fluctuations which characterize more southern latitudes. Regions south of 35°, also those in higher latitudes and west of Rocky mountains, partake of the subtropical type of curve, shown by Köppen to be similar to the tropical type, but with smaller amplitude. In these regions the 11-year period predominates over other periods.

Owing to the fact that the cloudiness and precipitation are light, the fluctuations of the surface temperature in the southern Plains States correspond more nearly to those of the free air than do those of stations east of the Mississippi, especially those east of the Appalachians. According to Schott the Cincinnati curve partakes of an intermediate character between the Atlantic type and that of the Mississippi basin.

Table 1 gives the dates of maxima and minima of the seven-year temperature variation. The interval maximum to maximum and minimum to minimum in consecutive sequence are given in the next column, and the last column shows the intervals smoothed by overlapping three-year means. Curve 13 is a plot of these smoothed intervals. Curve 12 is a reproduction of the curve shown

[a] Synchronous Variations in Solar and Terrestrial Phenomena, Astrophys. Journal, July, 1905, vol. 22, pp. 42-75.

on Chart 1 in my earlier paper (Astrophys. Journal, July, 1905). This curve shows the variations in the length of the 11-year sun-spot period. The successive intervals, maximum to maximum and minimum to minimum are plotted opposite dates nearly midway between the beginning and the end of the interval. The successive intervals have been joined by straight lines. A curve properly fitted to these points would, of course, more nearly approximate the true variation, and in doing so yield a somewhat greater amplitude of variation. It is further to be noted that the solar activity, one manifestation of the variability of which, is the varying rapidity of completion of a period, undergoes variation continuously and the length of a period, maximum to maximum or minimum to minimum, is the integrated effect of variations in activity which actually may change from an increase to a decrease or vice versa during this interval. Hence the true amplitude of the curve is somewhat greater than shown on the plot.

A comparison of curves 12 and 13 shows the synchronous nature of the variations in the length of the 11-year sun-spot period and in the length of the 7-year temperature period. The very long sun-spot period, about 1795, synchronizes with an increase of the length (to about 10 years) in the temperature period. A relatively long interval about 1880 shown by the two curves is another interesting feature. The fluctuations of the solar curve apparently precede slightly the terrestrial fluctuations. A similar retardation in the case of the fluctuations of the 36-year Brückner cycle was pointed out by myself in the paper previously referred to. Approximately seven years elapse between the epoch of occurrences of cold winters and the epoch of minimum length of the 11-year sun-spot period.

The average length of the long period shown by these curves has been about 25 to 28 years. Evidently the last century and early part of the present century mark a minimum phase in the secular variation in the length of

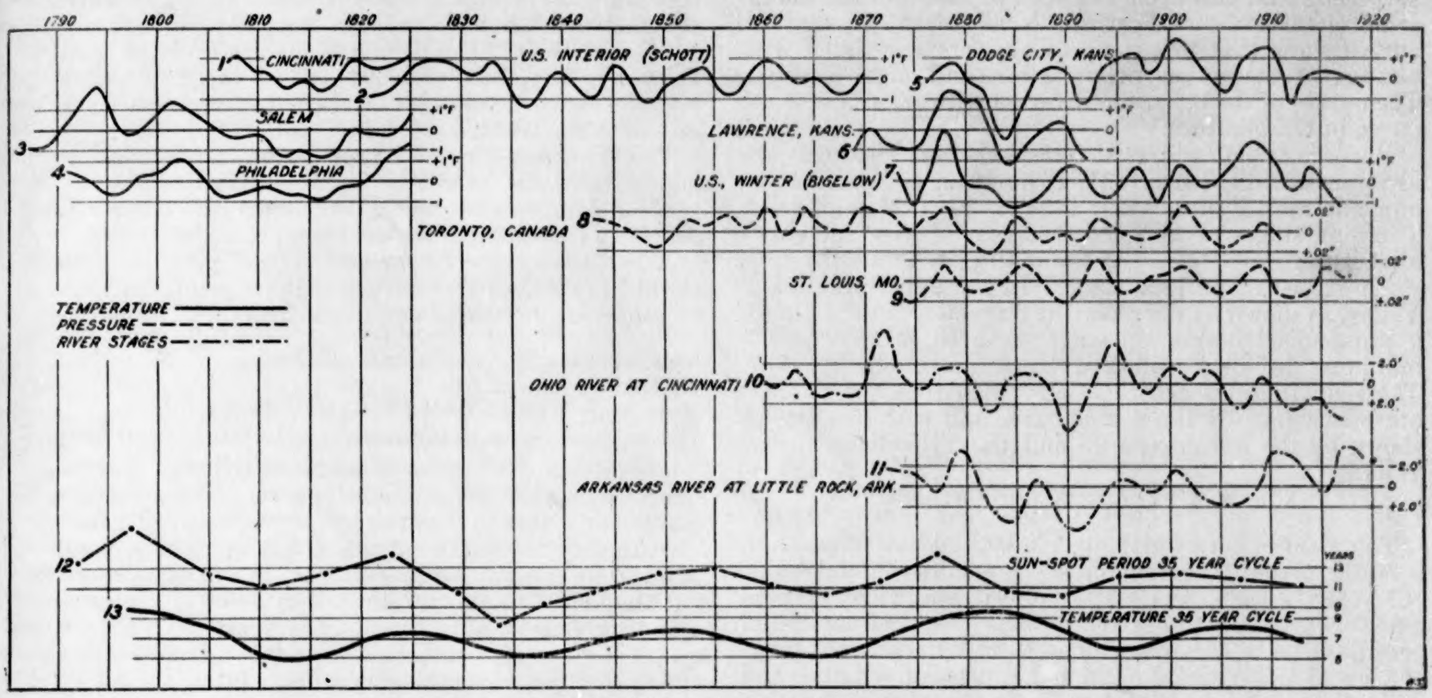


FIG. 1.—Variations of temperatures, pressures, and river stages in the United States east of the Rocky Mountains, and a comparison of the variation in the length of the 11-year sunspot period with that of the 7-year temperature period in a 35-year cycle.

TABLE 1.—*Dates of maxima and minima of the seven-year temperature variation.*

Max.	Min.	Interval.		Max.	Min.	Interval.	
		Actual.	Smoothed.			Actual.	Smoothed.
	1787				1857	7	7.0
1792		10		1860		6	6.0
	1797	10	10.0		1863	5	5.3
1802		10	9.0	1865		5	5.3
	1807	7	7.3		1868	6	5.7
1809		5	5.7	1871		6	6.7
	1812	5	5.0		1874	8	8.0
1814		5	5.0	1879		10	9.3
	1817	5	5.3		1884	10	9.3
1819		6	6.3	1889		8	8.0
	1823	8	7.3		1892	6	6.7
1827		8	7.3	1895		6	6.0
	1831	6	6.3		1898	6	6.3
1833		5	5.7	1901		7	7.3
	1836	6	5.7		1905	9	8.0
1839		6	6.0	1910		8	7.7
	1842	6	6.3		1913	6	6.7
1845		7	7.0	1916		6	
	1849	8	7.7		1919		
1853		8	7.7				

the 36-year cycle which I have shown to have a periodicity of about 300 years.

Curve 7 shows comparative fluctuations for the whole United States during the three winter months, December, January, and February, after a method used by Bigelow (American Journ. of Science, Aug., 1910). He gives for each month from 1873 to 1900 numbers representing positive and negative departures for the whole country, and the difference of these numbers represents the excess or deficiency of temperature which characterized the country as a whole. The units are arbitrary, but the variations are comparable from year to year. I have extended his tables to include 1918 and computed the average winter departures. A smoothed plot of these departures is represented by curve 7. This curve shows clearly 7-year fluctuations, which in the main synchronize with the Dodge City curve. The long period Brückner variation is well marked with maxima about 1878 and 1906 and minima about 1893 and 1919.

The 7-year variation in pressure is shown by curves 8 and 9, representing the Toronto and St. Louis series of observations. It has been found that the phases of the 7-year period in pressure are nearly synchronous over very extensive regions embracing areas as large as the United States. St. Louis well illustrates the character of this fluctuation for the interior of the country. The Toronto series carries the variation back to 1840. Observations at Providence extend the record back to 1832. This record shows pressure maxima in 1835 and 1840 and minima in 1837 and 1844. A tendency for high pressure slightly to precede low temperature, and vice versa, is clear from an inspection of the curves.

Curves 10 and 11 show fluctuations in the mean annual stage of the river at Cincinnati and Little Rock. The variations in the yearly amounts of precipitation over the watershed above these stations are well represented by these river-gage readings. The regularity of the 7-year cycle in the Little Rock record is remarkable and it is not surprising that this cycle has been observed in the fluctuation of this river at Fort Smith, as stated above. The curves show that low temperatures are associated with periods of maximum precipitation and high pressure. The curves of the latter are inverted with reference to the curve of temperature.

Records of high waters at Natchez, Miss., yield maxima as follows: 1814, 1823, 1831, 1836, 1842, 1849, and 1858, and minima in 1819, 1828, 1834, 1839, 1845, and 1855. The high stages of 1858–59 were general over the entire Mississippi watershed. At Cairo and St. Louis the 1858 stage exceeded the 1859 stage. In the upper Mississippi Valley, as shown by the record at Davenport and St. Louis, a pronounced maximum stage occurred in 1862 and a minimum in 1864, followed by a maximum in 1867. These fluctuations accord closely with those of temperature as shown by the Schott curve and with pressure as shown by the Toronto curve and the Providence observations.

A 7-YEAR PERIOD IN CROP YIELDS.

The yield of corn for the whole United States varies in a 7-year period. Maximum yields occurred about 1871, 1877, 1884, 1889, 1897, 1905, 1914, and 1920. These dates occurred at or shortly after the epochs of maximum precipitation. The importance from an economic point of view of this cyclical relationship between weather and crops can not be overestimated. Far-reaching effects resulting from this close relationship can also be traced in a 7 or 8 year period in industrial and business activity.

THE 7-YEAR PERIOD IN OTHER REGIONS OF THE GLOBE.

The 7-year period has been traced in European records of pressure. The dates of high and low winter pressure found by Maurer have been given above. The variations based on yearly means according to the researches of the writer are: Maxima, 1746, 1753, 1760, 1767, 1774, 1779, 1787, 1796, 1803, 1808, 1813, 1821, 1826, 1834, 1841, 1850, 1858, 1863, 1868, 1874, 1882, 1890, 1898, 1905, 1914. The dates of minima are: 1742, 1750, 1757, 1764, 1771, 1777, 1783, 1791, 1800, 1806, 1811, 1817, 1823, 1829, 1838, 1845, 1853, 1861, 1865, 1871, 1878, 1886, 1894, 1903, 1910. These epochs synchronize closely with those of the United States. On the other hand, the Iceland pressure varies oppositely, as follows: Maxima, 1844, 1854, 1859, 1866, 1871, 1878, 1887, 1894, 1901, 1909, 1916; minima, 1847, 1857, 1863, 1868, 1874, 1883, 1890, 1898, 1904, 1913.

The temperature in Europe varies generally opposite to that of the United States east of the Rocky Mountains. The records at Greenwich and Paris show maxima 1852, 1858, 1863, 1868, 1875, 1884, 1893, 1899, 1905, 1912; minima, 1854, 1860, 1865, 1871, 1879, 1888, 1895, 1902, 1909, 1917. This opposition between the temperatures of the United States and Western Europe is probably due to the periodical variation of the Iceland pressure. When the Iceland low is strongly developed, the winds over the eastern United States have a strong northerly component, while those of western Europe show an increase in the southerly component of the winds. On the other hand, when the Iceland pressure is high there is an increased frequency of cold, continental winds over western Europe while, at the same time, the winds over the United States have an increased southerly component.

The resultant direction of the wind at Providence, R.I.,[7] from 1830 to 1876 has varied in an approximately 7-year period. The years of extreme northerly deviation are 1831, 1837, 1842, 1847–1848, 1857, 1863, 1867, 1875. These years correspond closely to years of low temperature and low Iceland pressure. The years of extreme southerly deviation are 1834, 1839–1840, 1845, 1853, 1860, 1865, and 1870. The resultant direction of the wind at Portland, Me., has varied between extreme northerly points in 1876, 1883, 1891, and 1898, and extreme southerly points in 1871, 1879, 1887, and 1895.

The tendency for the 7-year period to predominate in higher latitudes accounts for the irregularities in the 11-year temperature variation shown by Köppen and others to characterize the cold temperate latitudes.

A multiple of the 7-year and 11-year periods is one of about 21 or 22 years which has been frequently mentioned by students of cyclical variations.

A MECHANISM OF CLIMATIC CYCLES.[1]

[Review[2] reprinted from the Meteorological Magazine, October, 1920, 55:205-206.]

One of the main lines of research followed in the attempt to forecast the general character of a season several months or a year in advance has been the investigation of "weather cycles." The cycles which we have been asked at one time or another to accept vary in period indefinitely, but the favorites are the sunspot cycle of 11.2 years and a shorter one of approximately 3 years. The sunspot cycle, in spite of a sufficient solar basis, has proved disappointing, its meteorological effects being always small and usually debatable. It is well developed only where the response of climatic to solar conditions is of the simplest, as, for example, on the west coast of Africa, where the rainfall, e. g., at Bathurst, shows three periodicities of 11 years, amplitude[3] 192 mm.; 3.2 years, amplitude 180 mm., and 2.1 years, amplitude 102 mm., together with a "secular variation" corresponding to that observable in sun spots since 1870. Even here the amplitude of the short period nearly equals that of the sunspot cycle. On the other hand, the three-year period is often very obviously developed, and its only apparent cause—the solar prominence cycle—seems insufficient. To meet this difficulty in the case of Java rainfall, C. Braak has put forward in this memoir a "resonance hypothesis." According to this hypothesis, there may be a purely terrestrial cycle of cause and effect, which completes itself and returns to its starting point in about

[7] Caswell. Results of Meteorological Observations made at Providence, R. I. Smithsonian Contrib. 443. 1882.

[1] Batavia, K. Magn. en Meteor. Observatorium. Verh. No. 5. Atmospheric variations of short and long duration in the Malay Archipelago, and the possibility to forecast them, by C. Braak. Batavia, 1919.

[2] See another review, MO. WEATHER REV., July, 1920, 48:414-415.

[3] *I. e.*, the coefficient a in the formula $R=\bar{R}+a \sin t$.

the same time as the solar prominence cycle. When this happens, the latter fixes the period of the former and greatly increases the range of its phenomena. The best known effect of "resonance" is the semidiurnal variation of pressure.

In the case of Java rainfall the chain of events is briefly as follows: Pressure variations at Batavia coincide with those at Port Darwin in Australia, but the latter have double the amplitude of the former. Consequently, remembering that we are dealing with the Southern Hemisphere, high pressure increases the strength of the east monsoon (November to April) and decreases that of the west monsoon (May to October). It happens that during the former high pressure causes low temperature and is self-sustaining, but during the latter high pressure causes high temperature. This in the course of two years penetrates to the upper air and reduces the pressure below normal. Consequently there is a three-yearly variation of pressure of a "saw-tooth" type, the curve rising slowly for two years and then sinking rapidly for one year. Note that the changes from low to high, or vice versa, can take place only in the west monsoon and the period is thus limited to exactly three years.

It is obvious that a similar sequence of events must take place at many localities near the Equator where conditions are suitable. An example is Lagos, Nigeria, where there is a marked three-year rainfall periodicity. Although pressure data are lacking, we may infer that this is analogous to the case of Batavia, the Sahara taking the place of northern Australia.

A self-regulating system of a different type has been described by W. Meinardus in the north Atlantic.[4] Here ice plays a part. A weak Atlantic circulation means ice at Iceland and little off Newfoundland; this raises the pressure to the east of Greenland and lowers it to the west, causing northerly winds over Baffins Bay and southerly winds at Iceland, so increasing the strength of the Atlantic circulation and reversing the ice conditions. The winter weather in western Europe is known to be influenced by the strength of the Gulf drift, and we may suppose the latter to be affected to some extent by the solar prominence period, acting perhaps only at certain seasons of the year. Hence there are indications of a forced periodicity of three years in the weather of western Europe.[5]

And here, it seems, we have the explanation of why these periodicities so frequently persist for a time, and then break down. For the solar prominence period is not exactly three years, but a few months longer, so that it will gradually outstrip the terrestrial period. After aiding the latter for a few cycles it will gradually come to oppose it, the periodicity will die out, or perhaps skip a year or two, and reappear at the wrong dates, when the resonance is reestablished. This has hitherto been ascribed to a failure of the cycle, but bearing in mind the new principle, it may be possible in the future to forecast these vagaries. Rainfall forecasts based on the modifications of the three-year period are in fact already being issued in Java, and there seems no reason why they should not be equally practicable in other tropical regions.—*C. E. P. Brooks.*

[4] Ann. Hydrogr., Berlin, 1904, p. 353. See further discussion of this and later contributions in MONTHLY WEATHER REVIEW, November, 1918, 46:510-512.
[5] See MONTHLY WEATHER REVIEW, August, 1920, 48:465-466.

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EFFECTS OF HEAVY RAINFALL ON PANAMA-CANAL SLIDES.

Among the engineering surprises attending the construction and operation of the Panama Canal may be mentioned the effects of the heavy isthmian rainfall on the troublesome slides that developed in the banks of the canal as excavation work progressed.

It was generally believed by engineers, as well as by the public, that these slides would be most active and troublesome during the season of heavy rainfall. As a matter of fact, the opposite proved to be the case. Practically all of the extensive deep-seated troublesome slides displayed greater activity in the dry season than during the rainy season. The explanation offered by geologists was that the cohesiveness of the material in the canal banks is greatest when the material is saturated by the heavy rains, enabling it to stand up better than it does during the dry season, when it dries out, tending to lose its cohesiveness and crumble under the weight superimposed upon it.

A type of superficial slide of small extent *has been* more prevalent during the rainy season—loose surface material sliding into the canal under the influence of heavy rainfall, but the mass of material involved has been too small to make the handling of these slides a serious problem.

For example, the troublesome *Cucuracha slide* pushed out across the canal channel during the construction period, with a slow, ponderous, glacierlike movement. This slide has been intermittently active from the early construction days down to the present time, but generally more active in the dry season. It gradually spread until it involved an area of more than 50 acres.—*H. G. Cornthwaite.*

NOTES, ABSTRACTS, AND REVIEWS.

NEW MARINE OBSERVATORY IN JAPAN.

Announcement has reached the Weather Bureau of the opening of the new marine observatory at Kobe, Japan, on August 26, last. This institution, which owes its existence to the business men of Kobe, will have for its principal aims researches on meteorological, oceanographical, and nautical subjects. Special attention will be devoted to the Pacific Ocean. Facilities will be provided for the repair and test of navigational instruments.

It is expected that publications of the observatory will be printed in European languages.

METHOD OF PREPARATION OF MARINE METEOROLOGICAL CHARTS.

The following data give an idea of the work required in preparing the charts showing the weather conditions over the North Atlantic Ocean, that appear in the Monthly Weather Review. The month of August, 1920, is taken as an example, and the results are based on the forms received up to October 16. A few reports were received after that date, but not enough to change the figures materially.

The number of Forms 1201-M for the month of August received up to date (Oct. 16) from reporting vessels in the North Atlantic Ocean are as follows: July–August, 124; August, 253; August–September, 112. The first and last are known as "split months," and it is assumed that the total number of observations are divided equally between the two months, and one-half of the sum can therefore be considered as August reports. This number is 118, which added to 253 gives 371 as the total number received for the month.

An examination of over 200 forms shows the average number of observations as 9.43, which multiplied by 371 gives the total number as 3,499.

It oftens happens that a number of vessels are so near the same position at Greenwich mean noon of a certain date that it is impossible to plot more than one of them, although the others may be useful in verifying the observations of the first. A number of observations are rejected on account of unreliable barometric readings, or because they were taken at local noon instead of Greenwich as well as for other reasons. While as stated before 3,499 observations were received, only 2,352, or 67 per cent, were plotted. The daily number of the latter varied considerably, the least being 61 on the 20th and the greatest 87 on the 2d. The means for the three decades of the months were 82, 71, and 74, respectively, and for the entire month 76. About 50 land stations were also plotted daily; these were taken from the United States and British daily weather maps, and the number varied slightly, as observations were sometimes missing.

Taken as a whole, the number of reports shows a gratifying increase during the last two years, especially over the steamer lanes. There are regions, however, in the north, as well as a large portion of the Caribbean Sea, which are seldom heard from, and efforts are being made to obtain the cooperation of shipmasters visiting these waters.—*F. A. Young, Marine Division, U. S. Weather Bureau, Washington, D. C.*

WANDERING STORMS.

[Reprinted from *Nature*, London, Nov. 4, 1920, p. 321.]

Wandering storms form the subject of an article by Prof. A. McAdie, of Harvard University, in the Geographical Review for July last. The communication is for the most part based on Sir Napier's Shaw's Manual of Meteorology, Part IV, published during the war, which discusses the relation of the wind to barometric pressure and the travel of cyclones. Prof. McAdie instances three unusual storm tracks dealt with by Sir Napier Shaw, and alludes to the need in forecasting of knowledge of recurving storms, with especial reference to the aviator and his long-distance flights. A remarkable instance is given by the author of the erratic travel of a disturbance from May 8 to June 6, 1910. This is tracked from the Strait of Juan de Fuca to the Grand Banks, when it is said to have recurved again and again and to have come back to the continent on May 26. It then merged with a storm that was moving north from Texas, and after meandering about to the east and northeast of Nova Scotia for 10 days, until June 6, the disturbance dissipated.

PROGRESS OF METEOROLOGY.

By W. H. Dines.

[Abstracted from *Nature*, Nov. 6, 1919, pp. 247-248.]

"The progress of meteorology during the last 50 years has been very marked, as may be seen by a casual reference to the current meteorological literature of the period 1865-1875; to a great extent it resembles the emergence of astronomy as an exact science from the old astrology, but it must be confessed that the Newton of meteorology has not yet appeared."

The article follows the development of the science from the mere seeking for recurrences in the weather, through the applications of the laws of thermodynamics and mechanics of the atmosphere, and finally, perhaps, the somewhat overardent application of mathematics. But the turn is for the better, and the value of mathematics as an aid to meteorological investigation can not be overestimated.

The problem of the meteorologist of middle latitudes has always been in the direction of the genesis of the moving cyclone and anticyclone, and this investigation has led far into the upper air, through the troposphere and into the stratosphere, where interesting and important correlations between temperature and pressure have been obtained. "[Over England] from 1 km. and upward there is a very high correlation, indeed, between temperature and pressure; between 4 and 8 km. the correlation coefficients are more than 0.85; they then fall off rapidly so that there is again no correlation at the boundary between the troposphere and the stratosphere. Above this, in the lower part of the stratosphere, the correlation is negative and reaches −.030, but falls off with increasing height." To the author's mind, the changes in the temperatures aloft are the results, rather than the causes of the pressure distribution.

In addition to the vast data obtained by sounding balloons, there is also an accumulation of information obtained from pilot balloons, a large part of which has not yet been discussed.

"* * * Meteorologists have good cause for congratulation in the steady progress that is taking place.—*C. L. M.*

ANNUAL REPORT OF THE BRITISH METEOROLOGICAL COMMITTEE.[1]

[Excerpts reprinted from *Nature*, London, Oct. 21, 1920, pp. 260-261.]

The Report of the Meteorological Committee for the year ending on March 31, last, marks the end of a definite stage in the development of the British Meteorological Service. During the year under review four notable developments occurred: The Office became attached to the Air Ministry instead of being in direct connection with the Treasury; (2) the work of the British Rainfall Organization was incorporated with that of the Office; (3) the coordination of the services of the Navy, Army, and Air Force, which developed during the war, was begun; and (4) inter-Dominion and international cooperation in meteorology, which had largely been in abeyance during the war, save for military purposes, began to take a more definite shape. One might add as a fifth important occurrence that the period of service of Sir Napier Shaw as Director of the Office came to an end at the close of the year, though he consented to remain in office until the appointment of his successor was carried through.

* * * The effect of the war in bringing to light the value of meteorological information is well gauged by the increase of the *personnel* of the Office. In 1914 the Staff of the Office comprised about 20 professional and 60 clerical and technical assistants, while on March 31, 1920, the establishment was 97 professional staff and 278 clerical and technical staff.

The inter-Dominion and international arrangements are still far from being stabilized, but one of the most important developments was a Conference of Dominion meteorologists, which concluded with the following resolution: "That this conference of representative meteorologists of the British Empire assembled together for the first time agree to continue as an association for the exchange of their views from time to time by correspondence upon scientific matters concerning the achievements, requirements, and organization of their services, and hereby elect Sir Napier Shaw their first president, and invite the members to submit rules for the guidance and acceptance of the association."

This conference had been preceded by the international meeting in Brussels of representatives of the scientific academies of the Allies, at which meteorology was amongst the subjects considered. A Geodetic and Geophysical Union was set up, one of its branches being meteorology with Sir Napier Shaw as chairman and Dr. Marvin (of the U. S. Weather Bureau) as secretary. A meeting in Paris followed, summoned by the French Government, at which a new international committee was appointed, with Sir Napier Shaw as president, in continuation of the old committee. A further complication arises out of the convention relating to aerial navigation, which formed part of the work of the Peace Conference, and by Annexe G regulates "the collection and dissemination of statistical, current, and special meteorological information."

What shape international cooperation may ultimately take is sufficiently obscure, but it is satisfactory to know that Sir Napier Shaw, who has been responsible for so great a development in the past, is to continue to act as president of the new International Committee.—*E. M. W.*

[1] Fifteenth Annual Report of the Meteorological Committee to the Lords Commissioners of His Majesty's Treasury for the Year ended March 31, 1920. Pp. 88. (Cmd. 948) (London: H. M. Stationery Office, 1920.) Price 9d. net.

ANNUAL REPORT OF THE CHIEF OF THE WEATHER BUREAU, 1919-20.

The Weather Bureau is still suffering from the ravages of war and the consequences of a great change in economic conditions. The rehabilitation of the service is now a most urgent need.

The forecast service, in addition to its usual routine, issued special weather forecasts for the Army and Navy balloon race, which started from St. Louis, September 25, 1919; the recruiting tour of the NC-4, which began in September, 1919, and lasted for several months; the trans-continental reliability aeroplane race, which began October 7, 1919. In July, 1919, a new form of forecasts, known as "Flying weather" was begun at the request of the War Department. Later this service was extended to the Post Office Department as an aid to the mail-route aviators.

In order to show the verification of the forecasts, a table is given in the Report. This table covers the five years, 1915-1919, inclusive, for each of the five forecast districts into which the United States is divided, and shows the percentage of verification of the a. m. 36-hour weather and temperature forecasts.[1]

Throughout the year cooperation with the Army and the Navy meteorological services has been not only maintained, but has been rendered considerably more effective than heretofore.

Owing to the growing importance of marine meteorology, the marine section of the Climatological Division of the Bureau was organized into a separate division on April 1, 1920.

The Report also contains information on the Bureau's work in the growing highway weather service, weather maps, river and flood warnings, mountain snowfall measurements, fruit frost-work, solar radiation investigations, instrumentations, seismology, and volcanology.

COMPOSITION OF THE ATMOSPHERE.[2]

By A. Krogh.

[Reprinted from Science Abstracts, Sect. A, Aug. 31, 1920, § 1042.]

Within the apparatus briefly described absolute determinations of CO_2, O, "N" (N + inert gases), and combustible gases may be made with an accuracy of 0.001 per cent. The percentage of combustible gases (whether hydrogen or not) is found to be below 0.0005 per cent and probably below 0.0002 per cent, much less than the commonly assumed value 0.003 per cent. "N" is very nearly constant, observed variations from the average being less than 0.003 per cent, and it is claimed that the average "N" percentage in the troposphere is a geophysical constant which can be ascertained within 0.001 per cent. Two analyses give the absolute composition at the surface as 0.030 per cent CO_2, 79.022 per cent "N" and 29.948 per cent O. In the streets of Copenhagen the CO_2 percentage is usually increased by 0.001-0.007 per cent above the normal 0.030 per cent, there being at the same time a deficit of oxygen. The author urges a thorough study, by the methods developed, of the composition of atmospheric air, including samples from great heights. The paper is printed in English.—*M. A. Giblett.*

[1] A discussion of this table, as well as extensive excerpts from the report, appears in the Bulletin of the American Meteorological Society for November, 1920, pp. 127-134.

[2] K. Danske Vidensk, Selskab. 1, No. 12, pp. 1-19, 1919.

THE LIGHT FROM THE SKY—II.[1]

The light received from any given area of the night sky is made up of (1) starlight, (2) scattered starlight, and (3) earthlight, the last including all light not due to the stars. Above 40° galactic latitude the starlight is a relatively small percentage of the whole, and can be computed from star counts; the *total* light received from any area may be photometrically measured.[2] It is found that the illumination not due to starlight is *not* uniformly distributed over the sky. The investigations of Van Rhijn [3] show a kind of zodiacal light extending over the whole sky, the intensity depending upon the celestial latitude and longitude. By finding the excess of this zodiacal brightness over its mean value for each latitude and longitude, and applying a correction equal to this excess but of opposite sign, to all the measurements, the latter are made independent of the azimuth; the difference between total observed illumination and corrected earthlight gives the starlight, even for galactic regions. The earthlight corrected for the zodiacal illumination consists of direct earthlight and scattered earthlight; applying a correction for the latter (Abbot, Astron. Jour., 1914, **28:** 130), the earthlight is found to increase toward the horizon, indicating illumination due to a permanent aurora. The total amount of light received from all the stars in both hemispheres, as computed from present material, is equal to 1,440 stars of magnitude 1.00 Harvard visual scale; Chapman (Monthly Notices, 1914, **74:** 450), has obtained, by very different methods, 900–1,000 for this figure.

Rayleigh has found the night sky to be yellower than the day sky (*Cf.* MONTHLY WEATHER REVIEW, 1920, **48:** 468), again indicating that the night illumination is not due to scattering by an elevated attenuated atmosphere.

A summary of all determinations of the brightness of the night sky is given by Burns,[4] as follows:

1. Newcomb, *Astrophys. Jour.*, 1901, **14:** 279	0.029
2. Burns., *ibid.*, 1902, **16:** 166	0.050
3. Townley, *Pub. Ast. Soc. Pac.*, 1903, **15:** 13	0.050
4. Fabry, *C. R.*, 1910, **150:** 272	0.036
5. Yntema, *Gron. Pub.*, 22	0.140
6. Abbot, *Astron. Jour.*, 1911, **27:** 20	0.075
7. Van Rhijn, *Astrophys. Jour.*, 1919, **50:** 347	0.130
8. Burns, *Jour. Brit. Ast. Assoc.*, 1914, **24:** 463	0.030

Evidently some source of error has not yet been eliminated. (1) Did not claim to be precise; (2) was in an unfavorable locality; (3), (4) were by photographic methods (out-of-focus star methods) and could not be expected to agree with the visual methods; (5), (6), (7), used Yntema's method, and (8) used a special photometer. Burns concludes, however, that different peculiarities among the eyes of different observers, and differing atmospheric conditions (even though imperceptible to ordinary observation), etc., would preclude the expectation of close agreement.

The results of observations on the scattering of light by dust-free pure gases [5] have led to attempts at a mathematical explanation [6] in terms of atomic and molecular structure.—*Edgar W. Woolard.*

[1] *Cf.* MONTHLY WEATHER REVIEW, June, 1920, **48:** 353–354.

[2] Yntema's method is to determine the absolute amount of light received per square degree at the pole by comparing the brightness of the sky there with that of an artificially illuminated disk of opal glass and then estimating the stellar magnitude of the disk by observing it from a distance such that it has the appearance of a star; the light of other regions of the sky may then be compared with that of the polar area by varying the illumination of an annular screen in a measurable way until it disappears against the background of the sky.

[3] P. J. Van Rhijn: On the brightness of the sky at night and the total amount of starlight. Astrophys. Jour., **1919**, **50:** 356–375.

[4] G. J. Burns: Brightness of the night sky. Astrophys. Jour., 1920, **52**; 123–126.

[5] Lord Rayleigh: A reexamination of the light scattered by gases in respect of polarisation, Proc. Roy. Soc., 1920, A, **79**; 435–450; **98**; 57–64.

[6] J. J. Thomson: On the scattering of light by unsymmetrical atoms and molecules Phil. Mag., 1920, (6), **40**; 393–413.

ON THE DIURNAL VARIATION OF TEMPERATURE IN THE ANTARCTIC.

By J. ROUCH.

[Abstracted from *Comptes Rendus*, Paris Acad., Nov. 2, 1920, pp. 866–869.]

After studying the inversions of temperature [1] observed at the station Pourquoi-Pas? on the Petermann Island (lat. 65° 10′ S., long. 66° 34′ W., Paris), in the Antarctic, the author has found an interesting peculiarity in the diurnal march of temperature on clear days, *i. e.*, days having cloudiness less than 5. In addition to the ordinary maximum occurring about noon, there is another maximum about midnight. This phenomenon is marked in winter and autumn, but does not appear in summer and spring. In the autumn, the principal maximum occurs about 13 h., and the secondary maximum about 2 h. Minima occur at about 7 h. and 22 h. In winter the principal maximum occurs at 1 h. and the secondary at 13 h. It is interesting to note that, in winter, the night temperature is higher than the day, sometimes as much as 4° C.

The diurnal variation of temperature seems to be unrelated to any of the other meteorological elements, with the exception of cloudiness. The effect of the sun, during the winter, is naturally very slight, and it is at these times that the maximum occurs at a time corresponding to night hours. This seems to be a general characteristic of temperature in the Antarctic since it has been confirmed by other observers.—*C. L. M.*

SMOKE-TRAVEL FROM GREAT FOREST FIRES IN RUSSIA.

[Abstract of note by Charles Rabot, *La Nature Suppl.*, Oct. 16, 1920, p. 121.]

A tremendous forest fire which has been raging in north Russia, northeast of Petrograd, has emitted great quantities of smoke. With an easterly wind, on August 29–30 a great cloud of smoke entered Sweden and the next day eastern Norway. On September 1 it reached the heads of the Norwegian fiords, and extended north to Falun in Sweden and Trondjem in Norway. On the 1st and 2d the smoke became so thick in the mountains of southern Norway that the people sought for a local forest fire. At Kristiania, 1,500 kilometers from the fires, the smoke was so dense and acrid that people closed their windows, so as not to be bothered by it.

Other cases of great smoke clouds [2] are cited, namely, one in 1857, when the smoke from a burning peat bog in Oldenburg (northwest Germany) covered all central Europe with a thick cloud, and another in 1913 (Afterpost, Kristiania), when smoke from a great forest fire in Canada reached Iceland and even Norway.—*C. F. B.*

METEOROLOGICAL SERVICE IN PALESTINE.

Mr. Perez W. Etkes, a member of the Signal Corps Meteorological Service during the war, has recently written a letter to the editor of the MONTHLY WEATHER REVIEW from Jaffa, Palestine, where he is now situated. In addition to his work as an engineer in the Palestine Water Commission, Mr. Etkes has been active in the establishment of a network of meteorological stations. This network has been put in operation under the direction of the Physical Department, at Cairo, and while the equipment is not complete at all stations, the effort is being made to get a well-organized and efficient meteorological service under way at the earliest possible time.—*C. L. M.*

[1] *Comptes Rendus*, 1920, t. 171, p. 498. Abstract in MO. WEA. REV., September, 1920, 48; p. 534.

[2] Cf. H. Lyman, Smoke from Minnesota forest fires. MO. WEATHER REV., November, 1918, 46: 506–510.

Alexander G. Supan, 1847-1920.[1]

Prof. Supan, famous geographer, whose death was recently announced, was born in Innichen, Tyrol, March 3, 1847. He completed his education at the universities of Graz, Vienna, Halle a. S., and Leipsic. In 1884 he became editor of *Dr. A. Petermann's Mitteilungen aus Justus Perthes' Geographischer Anstalt* and served in that capacity for 25 years. From 1884 to 1909 he held the professorship of geography at the University of Czernowitz, and the same position at the University of Breslau from 1909 on. Probably his best-known work is his *Grundzuge der physischen Erdkunde*, which reached its sixth edition in 1916. Of his works that particularly interest meteorologists may be mentioned: *The Cloudiness of the Earth*, an extensive discussion started by Behm and Wagner, which he completed; *Distribution of Rainfall over the Land-Surface of the Earth*, published in 1898; and *Statistics of the Lower Winds.*—*H. L.*

Dr. Max Margules.

Lieut. Col. E. Gold has prepared an obituary which appears in *Nature* for October 28, 1920, which discloses the sad circumstances of Dr. Margules' death, on October 4. It is said that "his death was due to starvation. He had been living on a pension of 400 crowns a month (which is equivalent to 8s.) [$1.40], and he was too proud to beg for assistance." Dr. Margules became secretary of the Meteorological Institute at Vienna in 1890, having entered the Austrian Meteorological Service in 1880 after studying at Vienna and Berlin. He was 64 years of age.

His work concerned itself chiefly with mathematical discussions of the mechanics of the atmosphere. Among the especially noteworthy works is mentioned the computation of the pressure oscillations of the atmosphere on a rotating globe, in which he found that the period would be exactly 12 hours if the temperature were $-5°$ C. In the Year Book of the Meteorological Institute of Vienna for 1903 he gave a comprehensive discussion of the energy of storms, arriving at the conclusion that "the source of storms is to be sought only in the potential energy of position."

To quote from Lieut. Col. Gold:

> Margules retired from active participation in the work of the Austrian Meteorological Service during the directorship of the late Prof. Pernter and applied himself to the study of chemistry. He fitted up a small laboratory in his own house, where he lived in comparative retirement. The present writer was saddened to see him there in 1909 entirely divorced from the subject of which he had made himself a master. Meteorology lost him some 15 years ago and is forever the poorer for a loss which one feels might and ought to have been prevented.

—*C. L. M.*

[1] An extensive obituary by H. Wagner appears in *Petermann's Mitteilungen*, July-August, 1920, 140-146.

BIBLIOGRAPHY.

RECENT ADDITIONS TO THE WEATHER BUREAU LIBRARY

C. FITZHUGH TALMAN, Professor in Charge of Library.

The following have been selected from among the titles of books recently received as representing those most likely to be useful to Weather Bureau officials in the meteorological work and studies.

Bates, D. C.
Climate of New Zealand. Wellington. 1920. 16 p. 21½ cm.

Berget, Alphonze.
Où en est la météorologie. Paris. 1920. 302 p. 19½cm.

Bergsträsser, Gotthelf.
Neue meteorologische Fragmente des Theophrast. Arabisch und deutsch. Herausgegeben von G. Bergsträsser, mit Zusätzen vorgelegt von Franz Boll. Heidelberg. 1918. 30 p. 24½ cm. (Sitzungsb. der Heidelberger Akad. der Wissensch. Philos.-historische Klasse. 1918. Abh. 9.)

Bölsche, Wilhelm.
Eiszeit und Klimawechsel. Stuttgart. 1919. 77 p. 21 cm.

Brockmann-Jerosch, H.
Baumgrenze und Klimacharakter. Zürich. 1919. 255 p. 24 cm. (Pflanzengeographische Kommission der Schweiz. naturforschenden Gesellschaft. Beiträge zur geobotanischen Landesaufnahme 6. Den Berichten der Schweiz. bot. Gesellschaft, Heft, 26, für die Mitglieder und den Tauschverkehr beigelegt.)

Chamber of Commerce of the United States.
Relation of weather and business in regard to temperature. Washington. 1919. 12 p. 27½ cm. [See Mo. WEATHER REV., Dec. 1919, 47:867.]

Eredia, Filippo.
Clima di Zauia (Tripolitania). Roma. 1920. 12 p. 23½ cm. (Estratto dal. Bol. informazioni, anno 8, no. 1-6.)
Clima di Zuara. Roma. 1919. 19 p. 23½ cm. (Estratto dal Bol. d'informazioni, Ott. 1919.)
Precipitazioni acquee in Palestina. Roma. 1920. 14 p. 23½ cm. (Estratto dal Bol. della R. Soc. geografica italiana. Fasc. 7-9, 1920.)

Fraps, G. S.
Moisture relations of some Texas soils. Austin, Tex. 1915. 36 p. 23 cm. (Texas agric. exper. station. Bull. 183.)

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Om frostskaden paa frugttræerne i Lier aarne 1915–1918. Kristiania. 1918. 32 p. 22½ cm. (Særtryk av "Norsk havetidende." Nr. 17–18, 1918.)

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Calcolo della densità dell' aria alle varie altezze fino a 10,000 metri, in base alle osservazioni italiane. Vigna di Valle. 1918. 18 p. 31 cm. (Battaglione dirigibilisti. R. Stazione aerologica principale di Vigna di Valle.)
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Climate of Korea and its probable effect on human efficiency. 59 p. 22½ cm. (Reprinted from Transactions of the Korea branch of the Royal Asiatic society, vol. 10, 1919.)

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Westman, J.
Stärke der Sonnenstrahlung im Mittelschwedischen Ostseegebiet März 1918–Mai 1919. Nyköping. 1920. 24 p. 31 cm. (Meddelanden från Statens meteorologisk-hydrografiska anstalt. Band 1, nr. 1.)

RECENT PAPERS BEARING ON METEOROLOGY AND SEISMOLOGY.

C. F. TALMAN, Professor in Charge of Library.

The following titles have been selected from the contents of the periodicals and serials recently received in the Library of the Weather Bureau. The titles selected are of papers and other communications bearing on meteorology and cognate branches of science. This is not a complete index of all the journals from which it has been compiled. It shows only the articles that appear to the compiler likely to be of particular interest in connection with the work of the Weather Bureau.

Astronomie. Paris. 34. année. 1920.
Raymond, G. Contribution à l'étude du mistral. p. 335–336. (juil.) [Effects on growth of trees.]
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Woglum, R. S. Value of weather records in fumigation. p. 110–111.

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J., D. La foudre globulaire et les travaux du Prof. I. Galli. p. 140–145. (mai-juin.)
Rossignol, Jules. Les feux follets méritent-ils une place et une théorie parmi les météores lumineux de l'atmosphère? p. 177–180. (juil.-août.)
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Shaw, Napier. Sir Joseph Norman Lockyer, K. C. B., LL. D., D. Sc., F. R. S. p. 181–182. (Sept.) [Obituary.]
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Exner, Felix M. Wind und Luftdruck nach Untersuchungen in England. p. 275–281. (Okt.)
Hellmann, G. Welchen Einfluss hat der Krieg 1914/18 auf die Meteorologie gehabt? p. 273–275. (Okt.)
Radakovic, M. Über Ableitungen der ablenkenden Kraft der Erddrehung. p. 296–297. (Okt.)
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SPECIAL OBSERVATIONS.

SOLAR AND SKY RADIATION MEASUREMENTS DURING OCTOBER, 1920.

By HERBERT H. KIMBALL, Meteorologist.

[Solar Radiation Investigations Section, Washington, Nov. 30, 1920.]

For a description of instruments and exposures, and an account of the method of obtaining and reducing the measurements, the reader is referred to this Review for April, 1920, **48:**225.

The monthly means and departures from normal in Table 1 indicate that solar radiation intensities were close to normal values at all stations except Washington, D. C., where they were decidedly below normal, due to the haze that prevailed during the second, third, and fourth weeks. Noon intensities of 1.57 calories per minute per square centimeter, measured at Santa Fe on the 15th and 28th, equal the maximum noon readings previously obtained at that station in October.

For the month as a whole there was an excess in the total radiation received on a horizontal surface at all three stations.

Skylight polarization measurements obtained on 10 different days at Washington give a mean of 56 per cent and a maximum of 64 per cent on the 6th. Measurements obtained at Madison on 12 days give a mean of 63 per cent, and a maximum of 76 per cent on the 29th. These are only slightly below average values for October for the respective stations.

TABLE 1.—*Solar radiation intensities during October, 1920.*

[Gram-calories per minute per square centimeter of normal surface.]

WASHINGTON, D. C.

Date.	8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon.
	75th meridian time.	Air mass. A. M.					P. M.				Local mean solar time.
	e.	5.0	4.0	3.0	2.0	*1.0	2.0	3.0	4.0	5.0	e.
	mm.	*cal.*	*cal.*	*cal*	*cal.*	*cal.*	*cal.*	*cal.*	*cal,*	*cal.*	*mm.*
Oct. 1	6.50	0.71	0.75	0.87	......	......	......	......	......	......	5.79
2	5.79	0.80	0.90	1.05	1.26	......	......	0.93	0.76	0.61	5.36
4	8.18	......	......	......	......	......	1.13	......	......	......	10.21
5	8.18	......	......	......	0.65	......	......	......	......	......	7.29
6	5.56	0.90	1.02	1.15	1.31	......	......	......	......	......	4.95
7	6.02	0.86	0.97	1.10	1.25	1.45	1.24	1.09	0.93	0.83	5.36
11	8.81	......	......	0.61	0.85	......	0.89	0.63	0.51	0.39	7.57
12	10.97	......	......	......	0.97	......	0.84	0.64	0.al	......	8.18
14	9.83	......	......	0.47	0.73	......	0.91	......	......	......	9.83
15	9.83	......	......	0.54	......	......	......	......	......	......	10.59
20	10.59	0.28	0.37	0.51	0.70	......	0.64	0.41	......	......	12.68
21	10.59	......	......	0.39	0.57	......	0.55	0.39	0.25	0.16	14.60
22	12.24	......	......	0.55	0.78	......	0.82	0.63	0.45	......	11.81
23	9.47	......	......	......	......	......	1.14	0.94	0.74	0.63	7.57
26	14.60	......	......	......	1.12	......	......	......	......	......	12.24
29	3.63	0.87	0.99	1.10	1.24	1.40	......	......	......	......	4.57
Means	......	**0.74**	**0.83**	**0.76**	**0.95**	**(1.42)**	**0.91**	**0.71**	**0.59**	**0.52**	......
Departures	......	**−0.01**	**+0.02**	**−0.13**	**−0.14**	......	**−0.17**	**−0.17**	**−0.15**	**−0.13**	......

TABLE 1.—*Solar radiation intensities during October, 1920*—Continued

MADISON, WIS.

Date.	8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon.
	75th meridian time.	Air mass. A. M.					P. M.				Local mean solar time.
	e.	5.0	4.0	3.0	2.0	*1.0	2.0	3.0	4.0	5.0	e.
Oct. 1	4.37	......	......	1.16	1.35	......	1.23	1.06	......	......	4.37
2	3.81	......	......	......	1.27	......	......	......	......	......	5.36
3	7.04	......	......	1.12	......	......	......	......	......	......	5.56
4	5.56	......	1.02	1.14	1.30	1.50	1.27	......	......	......	5.36
5	6.76	......	......	......	0.98	......	......	1.02	0.92	......	5.79
6	7.87	......	......	......	......	1.42	1.22	......	0.90	......	6.50
7	5.56	......	......	......	1.16	1.36	......	......	......	......	6.76
8	7.04	......	......	......	1.10	......	......	......	......	......	7.87
11	9.14	......	......	......	......	......	0.88	0.70	0.54	......	10.97
12	9.47	......	......	......	1.08	......	1.07	......	......	......	10.59
16	10.59	......	......	......	......	......	1.24	......	......	......	9.83
20	12.24	......	......	......	0.99	1.15	......	......	......	......	14.10
21	13.13	......	......	......	0.83	......	......	......	......	......	15.11
29	2.87	......	......	1.22	1.34	......	......	1.07	......	......	2.49
Means	......	......	**(1.02)**	**1.16**	**1.14**	**1.36**	**1.15**	**0.96**	**0.79**	......	......
Departures	......	......	**+0.13**	**+0.11**	**−0.02**	......	**−0.02**	**−0.05**	**−0.10**	......	......

LINCOLN, NEBR.

Date.	e.	5.0	4.0	3.0	2.0	*1.0	2.0	3.0	4.0	5.0	e.
Oct. 1	4.57	......	1.00	1.11	1.31	1.51	1.26	1.10	0.93	0.84	3.99
2	2.67	......	......	......	......	1.29	1.09	0.91	0.76	0.63	6.50
4	6.76	......	......	0.94	1.19	......	1.22	1.06	0.90	0.83	8.49
5	6.76	0.80	0.90	1.04	1.24	1.45	1.26	1.10	0.95	0.82	7.57
6	6.50	......	0.63	0.77	0.91	......	......	......	......	......	7.29
11	9.47	......	......	1.07	1.26	......	......	......	......	......	10.59
12	6.50	0.94	1.05	1.16	1.30	......	1.28	1.11	0.97	0.87	6.27
16	6.50	......	......	1.16	1.31	......	......	1.06	0.95	0.85	9.14
27	3.15	......	......	1.26	1.40	......	......	......	......	......	3.63
28	3.45	......	......	......	1.43	1.61	1.44	1.27	1.11	0.98	2.49
29	2.62	......	1.04	1.18	1.33	1.50	......	......	......	......	4.57
Means	......	**(0.87)**	**0.92**	**1.08**	**1.27**	**1.47**	**1.26**	**1.09**	**0.94**	**0.83**	......
Departures	......	**−0.04**	**−0.06**	**−0.04**	**−0.02**	......	**+0.01**	**+0.01**	**−0.01**	**−0.02**	......

SANTA FE, N. MEX.

Date.	e.	5.0	4.0	3.0	2.0	*1.0	2.0	3.0	4.0	5.0	e.
Oct. 2	5.56	1.03	1.12	1.28	......	......	......	......	......	......	4.37
4	4.57	0.99	1.06	1.18	......	......	......	......	......	......	3.81
5	6.50	0.98	1.08	1.19	......	......	......	......	......	......	3.81
8	4.57	1.06	1.17	1.29	......	1.64	1.42	1.28	1.17	1.06	4.57
15	4.17	......	......	......	1.49	......	......	......	......	......	2.36
21	3.45	......	......	......	......	......	1.44	1.24	......	......	1.12
22	2.87	......	......	......	1.45	1.60	......	......	......	......	2.49
26	3.30	......	......	......	......	......	1.40	......	......	......	3.45
27	3.81	......	......	......	......	......	......	1.34	1.24	......	3.45
28	2.74	......	......	......	......	1.65	1.48	......	......	......	3.25
Means	......	**1.02**	**1.11**	**1.24**	**(1.47)**	1.63	**1.44**	**1.29**	**(1.20)**	**(1.06)**	......
Departures	......	**−0.06**	**−0.04**	**+0.01**	**+0.09**	......	**+0.04**	**+0.05**	**+0.09**	**+0.18**	......

* Extrapolated.

TABLE 2.—*Solar and sky radiation received on a horizontal surface.*

[Gram-calories per square centimeter.]

Week beginning—	Average daily radiation. Washington.	Madison.	Lincoln.	Average daily departure for the week. Washington.	Madison.	Lincoln.	Excess or deficiency since first of year. Washington.	Madison.	Lincoln.
	cal.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*
Oct. 1	386	387	423	+60	+109	+67	−53	+2,133	......
8	355	278	318	+52	+28	−6	+309	+2,329	......
15	275	195	241	−8	−29	−51	+250	+2,127	......
22	258	156	343	−8	−48	+85	+191	+1,794	......

MEASUREMENTS OF THE SOLAR CONSTANT OF RADIATION AT CALAMA, CHILE, SEPTEMBER, 1920.

By C. G. ABBOT, Assistant Secretary.

[Smithsonian Institution, Washington, Dec. 3, 1920.]

NOTE.—The above report having been delayed in transmission, will be included in the next (November) issue of the REVIEW.—*Editor.*

WEATHER OF THE MONTH.

WEATHER OF NORTH AMERICA AND ADJACENT OCEANS.

NORTH ATLANTIC OCEAN.

By F. A. YOUNG.

The average pressure for the month was slightly below the normal at land stations on the coasts of Newfoundland and Nova Scotia, as well as in the southern part of Ireland and the Azores; it was somewhat higher than usual on the coast of the United States, south of Nantucket, and in the Gulf of Mexico, and on the east coast of England, while the positive departures were large over the northern part of Scotland.

According to reports received the number of days on which gales were reported was not far from the normal over the entire ocean.

The number of days with fog was apparently considerably less than usual over the Great Banks, American coast, and the greater part of the steamer lanes, while it was considerably above the normal in the vicinity of the British Isles, as in the 5° square that includes the southern part of England it was reported on 18 days.

On the 2d there was a disturbance of marked intensity central near latitude 50, longitude 35. This LOW moved rapidly eastward increasing in intensity, and on the 3d the center was about 300 miles west of the Irish coast, as shown on Chart IX.

The storm logs from different vessels are as follows:

Gothland, Belgian S. S.: Gale began on the 2d. Lowest barometer 29.50 inches at midnight on the 2d; position, latitude 48° 50′ N., longitude 30° 50′ W. End of gale on the 4th. Highest force of wind, 12; shifts of wind near time of lowest barometer WSW.-W.-WNW.-NW.

Stanmore, British S. S.: Gale began on the 2d. Lowest barometer 28.85 inches at 4 a. m. on the 3d; position, latitude 50° 16′ N., longitude 29° W. End of gale on the 5th. Highest force of wind 12; shifts of wind not given.

Arkansas, Danish S. S.: Gale began on the 3d. Lowest barometer 28.67 inches at 1 p. m. on the 3d; position, latitude 55° 12′ N., longitude 26° 55′ W. End of gale on the 4th. Highest force of wind, 11; shifts of wind, none.

Chart X, for October 4, shows that this disturbance moved but little during the next 24 hours, while it decreased somewhat in intensity and the storm area in extent. On the 5th the LOW was in nearly the same position as on the previous day, and was fast filling in, winds of from force 2 to 6 prevailing, except that in the southwest quadrants a few vessels experienced moderate northwesterly gales.

On the 1st, 3d and 4th fog was reported off the east coast of England and on the 1st and 4th in the vicinity of Newfoundland, and on the 5th, over the Grand Banks and at Halifax and Sydney, N. S. On the 6th, fog was encountered in the middle section of the steamer lanes, and on the 7th between the 40th and 45th parallels, and the 35th and 45th meridians. On the latter date a few reports of moderate gales were received from mid-ocean, and on the latter date the American S. S. *El Almirante* ran into a northerly gale off the coast of Georgia. Her storm log is as follows:

Gale began on the 6th. Lowest barometer 29.88 inches at 4 a. m. on the 9th; position, latitude 35° 55′ N., longitude 75° W. End of gale at 3 p. m. on the 9th. Highest force of wind, 11; shifts of wind N. by E.-NE.

On the 8th and 9th conditions were about the same as on the 7th, except that the moderate disturbance over the steamer lanes drifted slowly eastward, as on the 9th the center was about 300 miles west of the Irish coast, while southerly gales prevailed over a limited area in the easterly quadrants, on both days. Fog was reported over the western part of the steamer lanes on the 7th and over the British Island on the 8th and 9th.

On the 10th and 11th moderate weather was the rule over the entire ocean, except that on the latter date a few reports were received from vessels between the Azores and the Irish coast, that experienced moderate gales.

On the 12th there were two disturbances, the first being central near latitude 46°, longitude 52°, and the second near latitude 50°, longitude 15°. Both of these LOWS moved but little during the next 24 hours and decreased in intensity. The storm log from the British S. S. *Lancastrian* is as follows:

Gale began on the 11th. Lowest barometer 29.11 inches at 10 p. m. on the 11th; position, latitude 49° 30′ N., longitude 18° 22′ W. End of gale on the 13th. Highest force of wind, 9; shifts of wind NE.-E.-SE.-SSW.-S.

On every day from the 14th to the 28th, inclusive, fog was reported by some land station in England or Scotland, and on the 23d, 27th, and 28th, by vessels on the Grand Banks.

On the 15th and 16th there was a LOW central near the 45th parallel and 45th meridian, that afterwards developed into an exceptionally severe disturbance, as shown on Charts XI, XII, and XIII for October 17, 18, and 19, respectively.

Storm logs are as follows:

Oskaloosa, American S. S.: Gale began on the 16th. Lowest barometer 29.35 inches at 3 a. m. on the 18th; position, latitude 49° 37′ N., longitude 23° 20′ W. End of gale on the 19th. Highest force of wind, 10; shifts SE.-S.-SSW.

Direction and force of wind and barometer readings recorded by the observer on this vessel at different hours for the 17th and 18th are as follows:

October 17, 4 p. m., SSE.; force 9, 29.60 inches; 8 p. m., SE., force 9, 29.54 inches; midnight, SE., force 9, 29.45 inches; October 18, 3 a. m. south, force 9, 29.35 inches; 4 a. m., south, force 8, 29.41 inches; 8 a. m., SSW., force 5, 29.44 inches.

Barometer remained nearly stationary for next 24 hours, wind increasing to force of 9.

Inkula, British S. S.: Gale began on the 16th. Lowest barometer 29.05 inches at midnight on the 17th; position, latitude 46° 46′ N., longitude 41° 54′ W. End of gale on the 19th. Highest force of wind 12; shifts of wind NNW.-NNE. and back to N.

Lucigen, British S. S.: Sunday, October 17, latitude 50° 13′ N., longitude 20° 51′ W. Wind freshened from south, barometer at noon 30.10 inches; 4 p. m., apparent ship's time, 29.84 inches. By 8 p. m. the wind had reached gale force, with heavy sea running, and the barometer continued to fall until midnight October 18, when it was steady at 28.78 inches with no abatement in either wind or sea, and these conditions prevailed throughout the following day. On the 20th at 10 a. m. the wind shifted to NW., the barometer having risen to 29.18 inches. The wind, however, still maintained gale force with heavy rain squalls until midnight; it then came in squalls, each being less severe. At 8 a. m. October 21 the wind was quite moderate. Barometer 29.36 inches.

On the 20th this disturbance was in practically the same position as on the previous day, and it had decreased somewhat in intensity, and the storm area contracted in extent. The storm log of the *Hanover*, American S. S., follows:

Gale began on the 20th. Lowest barometer 29.28 inches at 9 a. m. on the 20th; position, latitude 46° 05′ N., longitude 24° 45′ W. End of gale on the 21st. Highest force of wind, 10: no shifts.

By the 21st this LOW had apparently drifted northward, though not enough observations have been received to determine the position accurately. On the 21st and 22d a few reports were received denoting moderate gales in mid-ocean on the former date, and in the eastern section of the steamer lanes on the latter.

On the 23d there was a LOW central off the east coast of Newfoundland, and a few vessels in the southwesterly quadrants encountered moderate northwesterly gales. This disturbance moved rapidly eastward and on the 24th was central near the 50th parallel and 40th meridian as shown on Chart XIV. During the next 24 hours the easterly movement of this LOW was comparatively slight, with decreasing intensity and gradual filling in. Storm logs are as follows:

Rotterdam, Dutch S. S.: Gale began on the 24th. Lowest barometer 28.75 inches at midnight on the 24th; position, latitude 50° 03′ N., longitude 16° 06′ W. End of gale on the 25th. Highest force of wind, 10; shifts S.-SSW.-NW.-WNW.

Northern Pacific, United States S. S.: Gale began on the 24th. Lowest barometer 28.98 inches at 5 a. m. on the 24th. Position, latitude 46° 50′ N., longitude 40° 41′ W. End of gale on the 24th, 11 p. m. Highest force of wind, 11; shifts 7 points to NW. at noon on the 24th.

Grampian Range, British S. S.: Gale began on the 23d. Lowest barometer 29.31 inches at 11.30 p. m. on the 23d; position, latitude 44° 00′ N., longitude 45° 44′ W. End of gale on the 25th. Highest force of wind, 11; shifts W-NW.

From the 26th to the 28th the conditions were comparatively featureless, with slight pressure gradients and light to moderate winds over practically the entire ocean.

On the 30th a LOW was central off the west coast of Ireland and reports were received from vessels between the twenty-fifth and thirtieth meridians that encountered moderate to strong northwesterly gales. This disturbance moved slowly eastward, increasing in intensity, and on the 31st the center was in the Irish Channel, while northwesterly gales prevailed over the territory between the forty-fifth and fifty-fifth parallels and the tenth and twenty-fifth meridians. Storm logs are as follows:

Venusia, British S. S.: Gale began on the 29th. Lowest barometer 29.64 inches on the 29th; position, latitude 53° 37′ N., longitude 30° 09′ W. End of gale on the 31st. Highest force of wind, 10; no shifts.

Eibergen, Dutch S. S.: Gale began on the 30th. Lowest barometer 29.37 inches on the 30th. Position, latitude 50° N., longitude 16° 45′ W. End of gale on the 31st. Highest force of wind, 10; steady from NW.

NORTH PACIFIC OCEAN.

By F. G. TINGLEY.

The closing days of September saw further typhoon activity in Asiatic waters, which continued into October. According to a report by Father Coronas, Chief of the Forecast Division of the Philippine Weather Bureau, which appeared in the September MONTHLY WEATHER REVIEW, a well developed and severe typhoon swept the Pacific between the Ladrones and the Loochoos from September 22 until the end of the month.

The British S. S. *Uncas*, Hong Kong (Sept. 23) for San Pedro, was involved in this storm on September 30 and October 1 when off the southeastern coast of Japan, the center of the storm passing over the ship during the early morning hours of the latter date.

Mr. G. F. Leechman of the *Uncas* has furnished the accompanying interesting graph (Fig. 1) prepared from readings of the ship's aneroid barometer, showing the pressure fluctuations during the passage of the typhoon, together with the following account of the weather experienced.

September 30.—Noon, strong wind from SSE., squally, rough sea, high S'ly swell; 8 p. m., moderate gale, violent squalls, high sea, overcast and dull; midnight, whole gale, terrific squalls of long duration, mountainous seas, heavy rain from 10 p. m.

October 1.—2:30–3:20 a. m., wind drops to force 4 and shifts to S., 10 minutes later backs to SE., and after changing variously finally blows from WNW.; confused seas, 60 to 70 feet high, isolated and seldom breaking; low misty clouds, occasional rifts, foggy. 8 a. m., strong wind (6, WSW.), high tumbling seas, cloudy sky, clear.

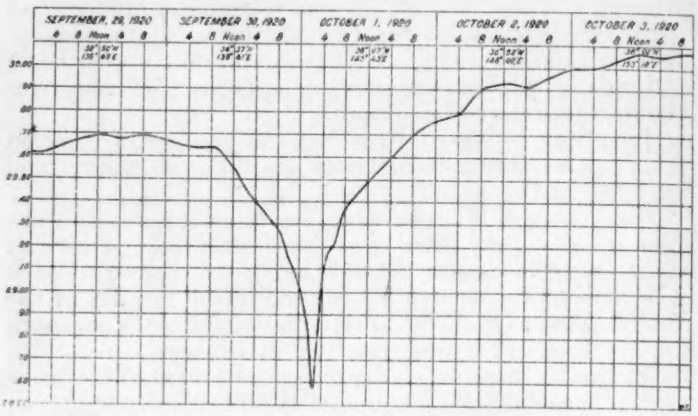


FIG. 1.—Typhoon of Sept. 29-Oct. 3, 1920, off the south and east coasts of Japan. Readings (corrected) of aneroid barometer on British S. S. *Uncas*. Time indicated is apparent time at ship. Duration of center, 50 minutes; approximate diameter, 10 to 15 miles.

The positions of the *Uncas* are shown in the figure.

The Japanese S. S. *Fushima Maru*, Capt. M. Machida, Yokohama (Sept. 28) for Victoria, experienced heavy weather in the same storm. Its influence was first felt on the 30th, the vessel on that date (at 10:04 p. m., l. m. t.) being in latitude 41° 21′ N., longitude 151° 07′ E. The lowest pressure recorded was 29.33 inches, which occurred at 4 a. m. of October 2, when in latitude 44° 26′ N., longitude 157° 58′ E. Highest force of wind 10; shifts of wind, SSE., S., SSW., SW.

At the beginning of the month a pronounced depression was central over southeastern Alaska and was causing westerly gales over the northern steamer route between the mainland and the Aleutians. This depression was one of a series which during the period from September 24 to the end of the month had moved from Bering Sea across southwestern Alaska.

The British S. S. *Methven*, Capt. H. James, Yokohama for Vancouver, was more or less involved in these storms between longitude 170° W. and 135° W., from September 26 to October 1, experiencing during the whole of this period westerly gales with fierce squalls and very high seas.

Aside from the tropical storms in Asiatic waters the principal disturbance of the month, as affecting shipping, was that of the last decade, which throughout the entire period from the 20th to the end of the month remained almost stationary over southwestern Alaska, causing shifting gales over the eastern portion of the northern steamer route. So far as the effects of this depression on shipping were concerned it appears to have reached its greatest intensity during the last three days of the month.

On the 29th the Japanese S. S. *Arabia Maru*, Capt. T. Saito, Yokohama for Victoria, when in latitude 49° 40′ N., longitude 154° 30′ W., recorded a pressure of 28.94 inches. This reading is apparently subject to a correction of about +0.15 inch. Highest force of wind 11, from SW. Shifts of wind, E. by N. to SW. On the 29th

the Japanese S. S. *Oridono Maru*, Capt. F. Ohno, Mororan for San Francisco, had a pressure reading of 28.34 inches, for which the correction appears to be +0.06 inch. Highest force of wind 10, from SE. Shifts of wind SE. to W.

On the 31st the Japanese S. S. *Katori Maru*, Capt. M. Yoshikawa, Yokohama for Seattle, when in latitude 49° 51′ N., longitude 144° 24′ W., recorded a pressure of 29.02 inches, corrected. Highest force of wind 11, from SSE., shifts of wind SE., SSE., S., SSW.

The *Katori Maru* had previously been involved in a typhoon on the 21st and 22d, when just out of port, the center passing the ship at about 1 p. m. of the 21st. Lowest barometer 28.98 inches, highest force of wind 11, from SSE., shifts of wind SSE. to NNW.

This typhoon was somewhat to the eastward of Balintang Channel on the 19th and thence had moved, during the 20th and 21st, first northerly, then northeasterly, along the coast of Japan. At 6 a. m. of the 22d the center was about 150 miles east by south of Yokohama. It is probable that it continued its northeasterly movement and merged with the large depression, already referred to, over southwestern Alaska.

Notwithstanding the heavy weather reported in October by some ships on the North Pacific, the majority traversed the waters of that ocean without experiencing any storm conditions of importance. On the whole the weather appears to have been more quiet than on the North Atlantic.

The following late report from the British S. S. *Mongolian Prince*, Capt. J. R. Gray, from Manila for Dalny and Colombo, furnishes information regarding a typhoon which prevailed during the closing days of September in the China Sea. Mr. J. McLoughlin, second officer and observer, reports as follows:

> September 29, 4 p. m.: (Ship's position latitude 22° N., longitude 116° 30′ E.) Typhoon warning from Hongkong by W/T. Typhoon center off Macclesfield Bank, stationary or recurving to NE. Barometer 29.34 inches, thermometer 79°. The above typhoon has been reported daily since noon of the 27th as probably passing over Hainan. Movements uncertain up to present. Typhoon apparently passed NE.'ly. 30th: (Ship's position at 8 a. m., latitude 19° 26′ N., longitude 114° 23′ E.) Heavy continuous rain during afternoon and evening, wind ENE., force 5, barometer falling, 29.36 4 p. m., thermometer 80°, surface water 82°, wet bulb 79°, dry bulb 78°, heavy swell coming from SW.

Nothing further is known regarding this storm.

NOTES ON WEATHER IN OTHER PARTS OF THE WORLD.

Alaska.—Dawson, Y. T., Oct. 11.—The Army dispatch steamer *Jacobs* and the steamer *Washburn* reached here to-day after several days' delay bucking through slush ice. * * * The Stewart River is reported free from ice, but is believed to be jammed near her mouth, locking in all boats above for the winter.—*Washington Post, Oct. 12, 1920.*

British Isles.—The outstanding characteristic of October was the abundant sunshine in the east and south of England. * * * The observer at Southport reports that it was the driest and yet the most humid October for at least 50 years, and that easterly winds were exceptionally persistent.

* * * The general rainfall expressed as a percentage of the average was: England and Wales, 58; Scotland, 67; Ireland, 127.

In London (Camden Square) the mean temperature was 51.9° F., or 1.7° F. above the average.[1]

Scandinavian countries.—The most noteworthy feature of the month was the remarkable persistence of high pressure over the Scandinavian area. The anticyclone which was established over that region throughout the last week of September persisted until October 13, when it withdrew in a southeasterly direction. By the 18th, however, another anticyclone had reached Scandinavia from the westward; this increased in intensity and persisted till the end of the month.[1]

Northwest Europe.— * * * In accordance with the pressure distribution, the general wind current over northwest Europe was between east and south.[1]

France.—There were some heavy rainstorms in France, especially in the south.[1]

India.—The monsoon rainfall has, on the whole, been deficient. Between the 1st and 21st of October Kashmir received an excess and Bombay and Deccan a normal amount of rain. The Bay Islands and Lower Burma had a fair amount, but other regions suffered from scanty rainfall.[1]

Japan.—Tokio, Oct. 1.—Scores of persons have lost their lives and widespread property damage has been done by a typhoon which struck the eastern coast of Japan to-day.

The storm centered around Yokohama, where 44 Japanese were drowned or killed by falling walls and 120 were seriously injured. Seventy-three houses were destroyed, 48 badly damaged, and 6,000 flooded.

* * * Reports from the Provinces state that many have been drowned.—*New York Evening Post, Oct. 2, 1920.*

Argentina.—Abundant rain fell in the Argentine during the first few days of the month, and the crop prospects were much improved. Some damage was, however, caused at the end of the month by sharp frost in the littoral Provinces.[1]

Australia.—A message received on the 23d states that light to heavy general rains have fallen through South Australia and an exceptional wheat harvest is now practically assured. Good rainfall gas also been experienced in New South Wales and Victoria.[1]

A cyclonic storm at Brisbane on Sunday [October 24] wrecked houses and factories, causing considerable damage.—*Samoa Times, Oct. 30, 1920.*

[1] The Meteorological Magazine, November, 1920, pp. 230, 236.

DETAILS OF THE WEATHER OF THE MONTH IN THE UNITED STATES.

CYCLONES AND ANTICYCLONES.

LOWS.

	Alberta.	North Pacific.	South Pacific.	Northern Rocky Mountains.	Colorado.	Texas.	East Gulf.	South Atlantic.	Central.	Total.
October, 1920....	6.0	1.0	2.0	0.0	1.0	1.0	0.0	1.0	0.0	12.0
Average number, 1892-1912..	4.2	1.3	0.8	0.5	1.7	0.7	0.4	0.5	0.3	10.3

HIGHS.

	North Pacific.	South Pacific.	Alberta.	Plateau and Rocky Mountains region.	Hudson Bay.	Total.
October, 1920............	3.0	3.0	4.0	0.0	1.0	11.0
Average number, 1892-1912..................	2.8	1.0	3.0	1.2	0.6	8.5

CYCLONES AND ANTICYCLONES—THE WEATHER ELEMENTS.

By M. C. BENNETT, Acting Chief of Division.

[Weather Bureau, Washington, D. C., Dec. 2, 1920.]

PRESSURE AND WINDS.

The month opened with relatively low pressure in the northeastern and northwestern portions of the country, while elsewhere it was above the seasonal average, especially in the great central valleys. High pressure persisted in the Southeast throughout the month, except for a few days about the middle of the third decade, when a southwestern low area moved eastward and northeastward across that region; this HIGH being similar to the summer type of pressure over that section. Rather frequent moderately low areas moved across the northern portion of the country during the first half of the month, resulting in pressure being relatively low in that section during much of this period. However, during the latter half of the month much more pronounced low pressure areas moved occasionally from the Far Southwest and West, northeastward and eastward across the country, and were followed by relatively high areas of moderate intensity. The month closed with high pressure over the northern portions of the Great Plains and Rocky Mountain regions and from the Mississippi Valley eastward, except in the far northeast, while elsewhere low pressure obtained.

For the month as a whole, the average pressure was above the normal from the Mississippi Valley and western Gulf States eastward and also in the southern Pacific area; elsewhere it was generally below the seasonal average. The departures from the normal were everywhere small, being in no case greater than 0.14 inch.

The distribution of atmospheric pressure during October resulted in southerly winds throughout the eastern Great Plains, the central valleys, the region of the Great Lakes, and eastward in the northern border States. They were northeasterly in the coastal portion of the south Atlantic States. Elsewhere variable winds prevailed.

TEMPERATURE.

The month opened with temperatures below normal in the middle and south Atlantic and Gulf States, and with frost as far south as central Louisiana and the northern portions of Mississippi, Alabama, Georgia, and South Carolina, while warmer weather was moving in over the Great Plains. Within the next few days there was a general warming up in all interior districts to readings above the seasonal average, and considerably warmer weather prevailed in the Atlantic coast States. About the middle of the first decade high temperatures for the season prevailed in the northern Great Plains, and on the 6th and 7th readings of 91° were reported from Bismarck, being the highest temperature of record for October for that place. On the other hand, temperatures somewhat below normal were quite general in eastern and southern districts during the latter half of the decade. The first few days of the second decade were marked by temperatures considerably above the normal in the Plains States, the upper Mississippi Valley, and in the region of the Great Lakes, but at the same time much cooler weather prevailed in the far Southwest. Temperature changes were unimportant throughout the second decade, except there was a sharp fall in temperature in the Southwest about the middle of the month. It was unseasonably warm throughout the interior of the country during this period and temperatures above the average persisted in all sections east of the Rocky Mountains. To the westward, however, lower temperatures prevailed, particularly in the Northwest where readings continued below normal. Temperatures continued unseasonably high during much of the third decade in nearly all eastern districts and were considerably below the seasonal average in most western sections. However, toward the latter part of the month much cooler weather overspread the eastern districts and freezing temperatures were experienced as far south as the northern portions of Alabama and Mississippi.

For the month as a whole unseasonably warm weather prevailed over much of the country east of the Rocky Mountains until near the close of the month, but temperatures continued below normal to the westward. In southeastern New England the warmest October in over 40 years was experienced, while in portions of New York and Pennsylvania it was reported as the warmest October in the history of the stations. During the last few days of the month much colder weather overspread all eastern districts, and by the morning of the 30th freezing weather prevailed southward to the northern portion of the cotton belt. In the Ohio and lower Missouri Valleys and from the central Great Plains northward the month averaged from 6° to 9° or more a day above normal, while west of the Rockies, except along the immediate Pacific coast, the temperatures averaged from 4° to 6° below the normal.

PRECIPITATION.

The tropical storm which was moving northward in the eastern part of the country at the close of September reached New England by the morning of the 1st. It caused heavy rainfall in nearly all Atlantic coast districts and was attended by shifting gales. Elsewhere little or no rain fell during the first several days of the month, except for showers in the Lake region and in the far Northwest. Shortly after the middle of the first decade precipitation was general from central California northward and in the northern Rocky Mountains; elsewhere little rain fell during this period. The beginning of the second decade was marked by rain in the northern

Rocky Mountain and Plateau regions. Fair weather was the rule in the Eastern States during the decade, but toward the middle of the period general rains fell in the West Gulf States, over the central and southern Great Plains, in the Mississippi Valley, and the western Lake region. The falls were heavy in Texas and the lower Missouri and upper Mississippi Valleys. At Taylor, Tex., 7.52 inches of rain fell within a period of 4 hours and 57 minutes; being the greatest 24-hour rainfall ever recorded during October at Taylor, and with the exception of April, 1915, the greatest 24-hour fall of record at that station. Rainfall was rather frequent in the far northwestern States, and toward the latter part of the decade rain had extended southward over the Pacific coast districts to central California, and during the last 48 hours of this period rain occurred in practically all districts west of the Rockies, and showers were received in most districts from the west Gulf region northward. Elsewhere fair weather prevailed, except for local widely scattered showers. During the first half of the third decade, rainfall was rather frequent in the western upper Lake region, the upper Mississippi Valley, and in the West Gulf district, with considerable snow in the higher elevations of the Rockies; the rainfall being heavy in Oklahoma. East of the Mississippi River fair weather was the rule, except for frequent rains in portions of the Florida Peninsula, and by the middle of the decade rain prevailed eastward to Georgia, eastern Tennessee, and central Ohio, the falls being heavy along the East Gulf coast. During the next few days precipitation occurred in all districts from the Mississippi Valley eastward, except in portions of the Florida Peninsula, the falls being heavy in the Ohio Valley and locally in the Atlantic coast States. The month closed with snow falling over the Plateau and northern Rocky Mountain districts.

For the month as a whole, the precipitation was light in most sections east of the Mississippi River, where large areas received less than 1 inch. At Mobile, Ala., the only precipitation during the month occurred from the 22d to 27th, nearly all falling within 24 hours; while at Montgomery, Ala., no rain fell from September 26 to October 24, being the longest period without rain in the history of that station; and Sault Ste Marie, Mich., had the least precipitation for October since the establishment of that station, and except for March, 1917, the least for any month of record for that place. Likewise Tampa, Fla., reports the month to have been the driest October in the history of that station. Moderate to fairly heavy amounts of precipitation were received from the west Gulf region northward to the lower Missouri Valley and central Great Plains, where many localities received from 4 to 8 inches. The amounts ranged from 1.5 to 2.5 inches in much of the Rocky Mountain and Plateau area, while along the immediate Pacific coast the monthly totals ranged from less than half an inch in southern California to about 14 inches at points in western Washington.

Considerable snow fell in the higher elevations of the central and northern Rocky Mountain States; at Lander, Wyo., 34.5 inches of snow fell during the month, the heaviest of record for October. Heavy falls were also reported in portions of Colorado, Nebraska, and the Dakotas, and unusually early snowfall occurred in the mountains of southern California and western Arizona.

RELATIVE HUMIDITY.

From the west Gulf region northward to the lower Missouri Valley and to the westward and northwestward nearly to the Pacific, the relative humidity was generally higher than the normal, which would naturally be the case with the fairly heavy precipitation received over much of that region. In most sections east of the Mississippi River the dry conditions existing during the month were indicated by the relative humidity being generally below the seasonal average, although in many instances excesses occurred. This was notably the case in portions of the Lake region and in the New England States, where despite the small amount of rainfall the relative humidity averaged above the normal.

SEVERE STORMS.

Severe storms were relatively infrequent. Six were reported, as follows:

Stevens Point, Wis., 11th: Property damage estimated at thousands of dollars was caused at this place by a terrific wind storm accompanied by hail.

Tyler, Tex., 14th: Four persons were killed and two injured when their home was destroyed by a severe windstorm about two miles from this place.

Winnsboro, Tex., 14th: A small tornado passed over this town, causing about $75,000 property damage.

Mexico City, Tex., 19th: A severe storm wrecked the "Marist Brothers' School" building, located about 6 miles from San Antonio.

Meridian, Wis., 20th: A tornado demolished many farm buildings, blew down a schoolhouse, and uprooted many trees in this vicinity.

Smithfield, Tex., 27th: Buildings and fruit trees were blown down and sugar-cane crop damaged by a severe wind and rain storm.

STORMS AND WARNINGS—WEATHER AND CROPS.

STORMS AND WEATHER WARNINGS.

Washington Forecast District.—The month was unusually quiet with long periods of fair weather and gentle to moderate winds. Previous to the 27th the only storm warnings issued were for the middle Atlantic coast at and between Hatteras and Cape Henry on the 9th, when a moderate disturbance was central some distance off the coast, and for the extreme southern Florida coast on the afternoon of the 18th, at which time a disturbance was apparently central immediately north of Cuba. However, this disturbance moved westward and lost intensity, after causing strong northeast winds in the Florida Straits. On the 27th a storm of marked intensity was over the region of the Great Lakes, moving east-northeast, and southwest storm warnings were ordered on the Atlantic coast at and north of Hatteras and on Lakes Erie and Ontario and northwest warnings on Lake Huron and eastern Lake Michigan. This storm increased in intensity during the 27th, causing gales on the lower Lakes, but decreasing in intensity during the following night as it moved to the lower St. Lawrence valley. The only strong wind reported on the Atlantic coast was 48 miles an hour from the south at New York, N. Y. A disturbance of wide extent was over the Plateau and southern Rocky Mountain regions on the morning of the 31st, with rapidly falling pressure over the southern Plains States. Noon special observations indicated that the storm would move rapidly northeastward over the upper Mississippi Valley and upper Lake region with increasing intensity. Accordingly, northeast storm warnings were ordered displayed at 6 p. m. on Lake Superior, northern Lake Michigan, and northern Lake Huron. These warnings were verified.

Frost warnings were issued for portions of the Lake region, the Ohio Valley, the Appalachian Mountain region, and the north Atlantic States on the 1st, 2d, 5th, 6th, and 7th, and they were well verified, as a rule, except in the lower Lake region, where the weather continued cloudy. There was a prolonged period of mild temperature after the 7th, and no further frost warnings were issued until near the close of the month. On the 28th warnings were issued for the region of the Great Lakes, the Ohio Valley, Tennessee, and the interior of Mississippi and Alabama; on the 29th for almost the entire district as far south as extreme northern Florida; and on the 30th for the Appalachian Mountain region and the Atlantic States north of Florida, except northern New England. All of these warnings were fully verified, except in New England and New York on the 29th.

The following special forecast was made on the morning of the 23d for the benefit of the contestants in the international balloon race which started from Birmingham, Ala., during the afternoon of that date:

> The outlook is for unsettled, showery weather to-night, Sunday, and probably Monday from Alabama northward over Tennessee, the Ohio Valley and the Lake region. Winds will be gentle easterly at the surface in Alabama and Tennessee this afternoon and to-night and southeast about 6 meters per second at elevation of 1,000 to 2,000 meters. Balloons will drift northwestward over western Tennessee, then northward over Kentucky, and probably northeastward from the Ohio Valley to the lower Lake region, but conditions not certain at this time.

—*Charles L. Mitchell.*

Chicago Forecast District.—Frosts were reported on the 1st from the Missouri Valley eastward to the limits of the region, these having been forecast the day before. Additional warnings were issued on the 1st for frosts in Wisconsin and Illinois, and these were also verified. The ensuing three weeks were continuously above the seasonal normal. Freezing temperature was forecast on a few dates for the State of Wyoming and frosts in the lower Missouri and upper Mississippi Valleys on the 24th. It was not, however, until the 26th, 27th, and 28th that general frost warnings were issued for the sections from the Plains States eastward, and these warnings were verified practically without exception.

Special frost warnings were, moreover, issued to the cranberry marshes of Wisconsin up to the 5th, when they were discontinued, as the harvest at that time had been completed.

Fire-weather forecasts were sent to the national and State forests of Minnesota during two critical periods in the month of October. The fire hazard was terminated by the general rains which fell October 19 and 20.

Live-stock warnings were issued on October 30 for southern Wyoming and the western portions of Nebraska and Kansas, as a storm of considerable intensity was developing in the far southwest. This storm moved directly eastward and northeastward over the Chicago forecast district with general precipitation, considerable snow falling in the western portion of the area. As a consequence of the warnings, stock men had an opportunity of leading their cattle to shelter.—*H. J. Cox.*

Denver Forecast District.—Freezing temperature and ocal frost were general in the latter part of the month. The important freezes were well covered by the warnings distributed. On the 19th and 20th, however, warnings of freezing temperature for eastern Colorado failed of full verification, owing to the slow eastward progress of the storm over the southern Rocky Mountain region. The storm was retarded by a stationary area of high barometric pressure in the Southeastern States, and eventually decreased decidedly in energy.

A rather severe storm for the season appeared over Arizona near the close of the month. It is not clear whether this storm developed in the southern part of a trough of low barometer, or moved northeastward across the Gulf of California. It was central over northwestern Arizona on the morning of the 30th. Freezing temperature warnings were issued for eastern Colorado and on the morning of the 31st live-stock warnings were distributed in northeast Colorado, with the advice that heavy snow was indicated. Freezing temperature warnings were extended to southern Colorado on the evening of the 31st. Severe weather followed in eastern Colorado. The temperature fell to 25° at Denver and 18° at Cheyenne by the evening of the 31st, and temperatures ranged from 10° to 30° above zero on the morning of November 1.—*Frederick W. Brist.*

New Orleans Forecast District.—No storm warnings were issued. On the 22d a moderate gale attended a thunderstorm on the extreme east coast of Texas, but there was no general storm without warnings.

Small-craft warnings were issued for the Texas coast on the 13th and for the Louisiana coast and the east coast of Texas on the 24th, for conditions that were somewhat threatening for such craft.

After the first day of the month there were no extensive frosts until the closing week, when frost occurred in most interior sections on the 28th and 29th, for which generally sufficient warnings were issued. Forecasts of possible

frosts were issued for the extreme northwestern portion of the district on the 22d, 23d, and 26th, and for the northwestern portion on the 24th; but it was not certain that the weather would clear and in most cases these frost forecasts were not verified, though frost temperatures largely occurred. The forecast of the 14th for frost in the Texas Panhandle, contingent on clear weather, was verified. A forecast of freezing in the Texas Panhandle by the morning of November 1 was issued on October 30 and was verified.

Fire-weather warnings for forested regions in Oklahoma were issued on the 7th, and for Arkansas and Oklahoma on the 13th, and wind and weather occurred as forecast.—*R. A. Dyke.*

San Francisco Forecast District.—Killing frosts occurred in Nevada and eastern Oregon during the latter part of the first decade, and in northeastern Washington and Idaho during the second decade.

The following advisory and storm warnings were issued during the month:

1st, small-craft warnings were ordered at Washington coast and Sound stations 11 a. m., and changed to southwest storm warnings 6 p. m., at all Washington and Oregon stations.

3d, southwest storm warnings ordered 6:30 p. m., at the mouth of the Columbia River and Washington stations.

4th, southeast storm warnings ordered all Washington and Oregon stations 6:30 p. m.

5th, southeast storm warnings ordered Eureka to Mendocino 11:30 a. m., and at Point Reyes and San Francisco 4 p. m.

6th, all warnings ordered down 8 a. m.

10th, southwest storm warnings ordered 6 p. m., mouth of the Columbia River and Washington stations.

13th, southeast storm warnings ordered 11 a. m., all Washington and Oregon stations.

15th, southwest storm warnings ordered 6 p. m., Washington coast, and advisory warnings sent to other Washington and Oregon stations.

16th, southwest storm warnings ordered Puget Sound stations 7 a. m.

17th, southeast storm warnings ordered 8:30 a. m., all Washington and Oregon stations, and extended south to Eureka 6 p. m.

20th, advisory warnings issued 8 a. m., all Washington and Oregon stations.

24th, advisory warnings issued 8:30 a. m., all Washington and Oregon stations.

30th, advisory warnings issued 8:15 a. m., Port San Luis to San Diego, and small craft warnings ordered Straits of Fuca 11:30 a. m.—*G. H. Willson.*

RIVERS AND FLOODS.

FLOODS DURING OCTOBER.

By H. C. FRANKENFIELD, Meteorologist.

Heavy rains over northern New England caused a severe flood on October 4 in the Winooski River and other streams of northern Vermont, and considerable damage was done. The flood was said to have been the greatest since that of October 4, 1869.

A moderate flood, but without flood stages being reached, occurred over the lower Connecticut River early in the month on account of heavy rains over the valley, and advisory warnings were issued on the morning of October 1, a crest of 12.5 feet being forecast for Hartford, Conn., by October 2. A stage of 13.1 feet (flood stage, 16 feet) occurred at 9 p. m., October 2, the excess over the forecast stage having been caused by the giving way of a portion of the flash boarding on the Holyoke Dam, 32 miles above.

The Santee River was in moderate flood at the close of September and additional heavy rains on September 30 drove the river to a stage slightly in excess of the flood stage, Rimini and Ferguson, S. C., reporting stages of 12.9 and 12.4 feet, respectively (flood stage, 12 feet). There were no losses, as the previous high water kept live stock from the swamps. There were no other floods east of the Mississippi River.

There were heavy rains over the Southwest during the early part of the third decade of the month, with resulting floods in some of the rivers of Oklahoma and Texas. There was a local flood in the Sulphur River of northwest Texas, with a crest stage of 22.6 feet, 2 feet above the flood stage, at Ringo Crossing. The river was above the flood stage for six days.

The North Fork of the Canadian River was in flood during the last week of the month, and the lower river remained so until November 8. Crest stages occurred as indicated in the second table following.

Warnings of the flood were first issued on October 22, and as often thereafter as occasion required, and, so far as is known, they were issued in ample time for farmers to protect themselves against loss. The greatest damage was done in Oklahoma City, where the breaking of the levees resulted in the flooding of the low industrial and residential districts. No lives were lost.

The upper Trinity River of Texas was also in flood about the same time, although it subsided before the close of the month. Warnings were issued on October 24 and 25, one day in advance of the flood, and proved to be timely and accurate. Crest stages are given below. Losses were negligible, as the warnings enabled the removal of all stock from the overflowed lands before the arrival of the floods.

The Colorado River of Arizona was generally above the flood stage of 7 feet during the first three weeks of the month, with a maximum stage of 9.1 feet on October 3.

Estimated losses by floods.

River and district.	Farms, buildings, machinery, live stock, etc.	Suspension of business.	Value of warning.	Tangible property, roads, bridges, etc.	Crops matured.	Crops prospective.
North Canadian, Oklahoma, Okla.	(1)	(1)	(1)	$250,000	.....	.....
Trinity, Dallas, Tex.	(2)	None.	(1)	(2)	(2)	None.

[1] Impossible to estimate. [2] Negligible.

Flood stages during month of October, 1920.

River and station.	Flood stage	Above flood stages—dates. From—	To—	Crest. Stage.	Date.
Atlantic Drainage:	*Feet.*			*Feet.*	
Susquehanna. Oneonta N. Y.	12	1	2	14.3	1
Santee: Rimini, S. C.	12	1	5	12.9	3
Ferguson, S. C.	12	2	9	12.4	5
Mississippi Drainage:					
North Canadian: Woodward, Okla.	3	22	27	7.8	22
Canton, Okla.	3	23	25	7.3	24
Oklahoma, Okla.	12	29	(1)	13.3	30
Sulphur: Ringo Crossing, Tex.	20	24	29	22.6	26
West Gulf Drainage:					
Trinity: Dallas, Tex.	25	25	29	31.1	26
Colorado: Parker, Ariz.	7	1	19	9.1	3

[1] Continued into November.

MEAN LAKE LEVELS DURING SEPTEMBER.

By UNITED STATES LAKE SURVEY.

[Dated: Detroit, Mich., Oct. 6, 1920.]

The following data are reported in the "Notice to Mariners" of the above date:

Data.	Lakes.[1]			
	Superior.	Michigan and Huron.	Erie.	Ontario.
Mean level during September, 1920:	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Above mean sea level at New York	602.81	580.87	572.39	245.47
Above or below—				
Mean stage of August, 1920	−0.12	−0.14	−0.26	−0.15
Mean stage of September, 1919	+0.28	+0.06	−0.36	−1.39
Average stage for September, last 10 years	+0.17	+0.20	−0.02	−0.72
Highest recorded September stage	−1.27	−2.56	−1.55	−2.14
Lowest recorded September stage	+1.32	+1.21	+1.11	+1.47
Average relation of the September level to—				
August level	....	−0.20	−0.20	−0.40
October level	....	+0.20	+0.30	+0.40

[1] Lake St. Clair's level: In September, 575.44 feet.

MEAN LAKE LEVELS DURING OCTOBER.

By UNITED STATES LAKE SURVEY.

[Dated: Detroit, Mich., Nov. 4, 1920.]

The following data are reported in the "Notice to Mariners" of the above date:

Data.	Lakes.[1]			
	Superior.	Michigan and Huron.	Erie.	Ontario.
Mean level during October, 1920:	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Above mean sea level at New York	602.68	580.55	572.05	245.29
Above or below—				
Mean stage of September, 1920	−0.13	−0.32	−0.34	−0.18
Mean stage of October, 1919	+0.27	−0.10	−0.42	−1.06
Average stage for October, last 10 years	+0.05	+0.08	−0.10	−0.52
Highest recorded October stage	−0.88	−2.39	−1.65	−2.52
Lowest recorded October stage	+1.10	+0.95	+1.25	+1.62
Average relation of the October leve to—				
September level	....	−0.20	−0.30	−0.40
November level	....	+0.20	+0.30	+0.20

[1] Lake St. Clair's level: In October, 575.14 feet.

EFFECT OF WEATHER ON CROPS AND FARMING OPERATIONS, OCTOBER, 1920.

By J. WARREN SMITH, Meteorologist.

October was generally warm and dry, with abundant sunshine, in nearly all sections east of the Rocky Mountains, except that heavy rainfall occurred at some points in the west Gulf and lower Great Plains areas. These conditions were ideal for maturing fall crops and for outdoor work. Work was interrupted to a considerable extent, however, in some Rocky Mountain sections and in the far Northwest by stormy weather, with considerable snowfall.

The frost that was general at the end of September and the first of October in the principal corn-growing States resulted in very little damage to corn, as the crop had matured rapidly during the preceding two weeks and was mostly out of frost danger. Some late corn was injured in Illinois, but, on the whole, the crop was benefitted by the cool weather. Thereafter generally fair weather, with abundant sunshine, produced conditions very favorable for maturing the very late corn, and for harvesting and drying the crop, although husking and cribbing were checked by rain during the last decade of the month from Iowa and Missouri westward.

October was mostly dry, with moderate temperatures, in the cotton belt, except for considerable rainfall in the more western districts. Cotton opened rapidly, and the weather was very favorable for harvesting, except that rain the last half of the month interrupted picking in some western sections, particularly in Texas and Oklahoma. Some damage resulted to open cotton by rain in central Texas, western Arkansas, and in most sections of Oklahoma. The first general frost of the season occurred in the northern portion of the belt on the 29th and 30th, but no material damage resulted.

Rain was needed most of the month for seeding winter grains in many sections east of the Mississippi River, and the germination of winter wheat was rather poor in some areas. Soil moisture was generally sufficient, however, from the western Gulf region northward where seeding and germination was accomplished under favorable conditions. Wheat, especially, promised the establishment of a good root system before cold weather in the Great Plains States. At the close of the month the rain had set in over most eastern sections where drought had prevailed.

Pastures needed rain badly in the eastern States, where they were short and dry throughout the month, but west of the Mississippi River conditions were more favorable, and pastures and ranges maintained their former good condition. The rains and snows improved the ranges in the Rocky Mountain States and far Northwest and stock continued in good to excellent condition in these sections. They were largely on winter ranges by the latter part of the month.

It was too dry for truck in much of the South, but cool weather the first of the month was favorable for sugar-cane in the lower Mississippi Valley. Sugar-beet harvest made mostly satisfactory progress, except for some delay by stormy weather in the Northwest. The weather was favorable for the harvest of deciduous fruits, and satisfactory yields were saved in good condition. Apples, especially, were plentiful in all sections of the country where that crop is of importance. Oranges were sizing up nicely in California and citrus fruits were maturing satisfactorily in Florida, with steadily increasing shipments.

CLIMATOLOGICAL TABLES.*

CONDENSED CLIMATOLOGICAL SUMMARY.

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course the number of such records is smaller than the total number of stations.

Condensed climatological summary of temperature and precipitation by sections, October, 1920.

Section.	Temperature.								Precipitation.					
	Section average.	Departure from the normal.	Monthly extremes.						Section average.	Departure from the normal.	Greatest monthly.		Least monthly.	
			Station.	Highest.	Date.	Station.	Lowest.	Date.			Station.	Amount.	Station.	Amount.
	°F.	°F.		°F.			°F.		In.	In.		In.		In.
Alabama	64.7	+0.4	Wetumpka	94	12	St. Benard	24	30	1.12	−1.54	Mobile	4.65	Cochrane	0.05
Arizona	59.4	−2.7	Aztec	107	2	Lakeside	00	22	1.42	+0.61	Payson	4.05	2 stations	0.00
Arkansas	64.2	+2.2	Pine Bluff	93	18	Dutton	25	28	4.39	+1.68	Texarkana	8.18	Magnolia	1.66
California	57.0	−4.1	Blythe	115	7	Portola	9	31	2.53	+1.08	Crescent City	14.24	Llano	0.00
Colorado	45.9	−0.7	2 stations	91	5†	Crested Butte	−6	12	1.76	+0.32	Cuchara Camps	5.91	La Porte	0.20
Florida	71.2	−1.8	3 stations	92	11	2 stations	32	29	1.90	−2.75	Jupiter	9.93	3 stations	0.00
Georgia	64.6	−0.2	2 stations	94	11	Adairsville	27	30	0.94	−1.87	Valdosta	2.34	Norcross	0.28
Hawaii (September)	74.7	+0.1	Mahukona	94	30	Glenwood	51	2†	4.48	−0.97	Eke Maui	18.50	7 stations	0.00
Idaho	44.0	−2.1	Weiser	92	5	Irwin	2	23	2.51	+1.02	Hereford	6.11	Murphy	0.80
Illinois	60.7	+5.7	3 stations	90	4†	Mt. Carroll	19	29	2.06	−0.32	White Hall	3.55	Morris	0.85
Indiana	60.2	+5.9	Huntingburg	94	14	Veedersburg	20	30	2.14	−0.33	Whitestown	4.86	Shoals	1.08
Iowa	57.7	+6.9	Waterloo	90	11	5 stations	15	29	2.13	−0.33	Charles City	4.64	Williamsburg	0.48
Kansas	60.5	+3.8	La Crosse	97	10	Oberlin	16	28	2.83	+1.04	Ashland	7.26	Chapman	0.80
Kentucky	61.0	+3.2	Beattyville	93	21	6 stations	24	30	1.64	−0.86	Paducah(Lone Oak)	4.00	Mayfield	0.15
Louisiana	68.4	+0.5	Donaldsonville	94	11	Robeline	31	28	3.13	+0.20	Lakeside	7.40	Delta Farms	1.00
Maryland-Delaware	60.3	+3.6	Western Port, Md	91	21†	Oakland, Md	25	3†	0.82	−2.16	Public Landing, Md	1.61	Baltimore, Md	0.17
Michigan	56.0	+7.3	Cassopolis	91	20	2 stations	12	29	1.80	−0.84	Calumet	4.22	Sault Ste. Marie	0.18
Minnesota	52.7	+7.2	Ada	91	6	Angus	8	28	1.75	−0.30	Mora	4.99	Warren	0.19
Mississippi	65.8	+1.0	2 stations	93	16†	Corinth	28	30	1.55	−1.21	Bay St. Louis	3.50	Agricultural College	0.00
Missouri	61.3	+4.3	Caruthersville	93	23	2 stations	18	29	2.89	+0.25	Neosho	6.09	Downing	0.90
Montana	44.4	+1.6	Billings	95	5	Bowen	−2	23	1.15	+0.03	Adel	3.22	2 stations	T.
Nebraska	55.1	+4.2	2 Stations	95	4†	Gordon	6	28	2.19	+0.60	Elm Creek	6.75	Ainsworth	0,45
Nevada	48.0	−2.7	Logandale	99	5	Via	4	31	1.05	+0.24	Mahoney Ranger Station.	3.67	Mina	T.
New England	54.7	+6.2	Waterbury, Conn	88	21	Woodland, Me	18	9†	1.96	−1.68	Somerset, Vt	6.10	2 stations	0.52
New Jersey	59.0	+4.8	2 stations	87	21†	Culvers Lake	25	30	1.80	−1.86	Boonton	4.53	Bridgeton	0.55
New Mexico	52.0	−0.5	2 stations	99	8	Senorito (near)	2	21	1.80	+0.53	Nara Visa	4.86	Olive (near)	0.02
New York	55.7	+5.8	Troy	88	9	Mohonk Lake	20	30	2.07	−1.29	Volusia	5.56	Elmira	0.57
North Carolina	60.5	+1.2	3 stations	90	15†	Waynesville	18	30	0.95	−2.54	New Bern	4.30	Statesville	0.00
North Dakota	49.4	+5.6	3 stations	92	6†	Napoleon	6	28	0.52	−0.48	Beach	1.51	3 stations	0.00
Ohio	58.5	+5.3	6 stations	89	19†	2 stations	21	31	1.97	−0.59	Hillhouse	3.54	McArthur	0.75
Oklahoma	63.7	+2.1	Mutual	98	4	Kenton	23	28	5.43	+2.92	Calvin	10.05	Goodwell	1.15
Oregon	48.4	−2.1	Grants Pass	88	2	Blitzen	4	31	3.35	+1.35	Deadwood	14.28	Warmspring	0.27
Pennsylvania	57.5	+5.2	3 stations	88	13†	2 stations	22	7	1.67	−1.79	Erie	4.67	Arendtsville	0.50
Porto Rico	78.5	+0.3	Utuado	99	2	Aibonito	54	7†	6.79	−1.69	Inabon Falls	16.10	Arecibo	1.40
South Carolina	64.1	+0.5	3 stations	92	13†	Walhalla	25	30	0.76	−2.29	Kingstree	2.44	Charleston	0.06
South Dakota	53.2	+5.9	Hardingrove	95	5	Pollock	6	28	1.07	−0.48	Yankton	2.46	Pollock	0.15
Tennessee	61.3	+2.1	Clarksville	92	18	Mountain City	17	30	1.00	−1.60	Union City	3.63	Greensville (near)	0.00
Texas	68.0	+0.5	Alice	100	15	Romero	26	30	3.82	+1.20	Anahuac	14.92	El Paso	0.57
Utah	45.2	−2.2	St .George	94	3	Blacks Fork	−6	24	2.91	+1.77	Silver Lake	8.58	Lemay	0.27
Virginia	60.3	+3.1	2 stations	90	15†	Burkes Garden	20	30	0.60	−2.58	Callaville	2.03	Blacksburg	0.04
Washington	48.2	−0.9	Wheeler	91	1	Wilbur	15	31	4.11	+1.32	Silverton	17.60	Maryhill	0.09
West Virginia	57.5	+2.4	Glenville	90	21	2 stations	21	30†	1.15	−1.86	Dam Twenty, O. R.	2.53	Upper Tract	0.10
Wisconsin	55.0	+6.9	Prairie du Sac	89	22	Prentice	9	29	2.20	−0.40	Grantsburg	5.24	Prairie du Sac	0.47
Wyoming	43.2	−0.5	Gillette	94	5	Gallatin	−15	25	1.31	+0.28	Lander	4.45	Powell	T.

* For description of tables and charts, see this REVIEW, January, 1920, p. 54.

†Other dates also.

TABLE I.—*Climatological data for Weather Bureau stations, October, 1920.*

Districts and stations.	Elevation of instruments: Barometer above sea level.	Elevation of instruments: Thermometer above ground.	Elevation of instruments: Anemometer above ground.	Pressure: Station, reduced to mean of 24 hours.	Pressure: Sea level, reduced to mean of 24 hours.	Pressure: Departure from normal.	Temperature of the air: Mean max. + mean min. ÷ 2.	Temperature of the air: Departure from normal.	Temperature of the air: Maximum.	Temperature of the air: Date.	Temperature of the air: Mean maximum.	Temperature of the air: Minimum.	Temperature of the air: Date.	Temperature of the air: Mean minimum.	Temperature of the air: Greatest daily range.	Mean wet thermometer.	Mean temperature of the dew-point.	Mean relative humidity.	Precipitation: Total.	Precipitation: Departure from normal.	Precipitation: Days with 0.01 inch or more.	Wind: Total movement.	Wind: Prevailing direction.	Wind: Maximum velocity: Miles per hour.	Wind: Maximum velocity: Direction.	Wind: Maximum velocity: Date.	Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow, sleet, and ice on ground at end of month.
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles.								0–10	In.	In.
New England.							56.3	+5.9										77	1.64	-0.2										4.6		
Eastport	76	67	85	29.91	29.99	-0.01	52.3	+5.7	68	19	59	37	15	45	27	48	44	79	2.18	-1.7	5	7,704	s.	36	s.	1	13	10	8	5.1	0.0	0.0
Greenville, Me.	1,070	6	....	28.84	30.01	......	50.4	......	74	9	60	30	24	40	38	....	....	....	3.22	......	10	......		....		....	12	4	15	....	T.	T.
Portland, Me.	103	82	117	29.92	30.04	.00	55.4	+6.3	79	21	64	35	30	47	30	49	44	72	1.12	-2.5	7	6,512	sw.	42	se.	1	16	7	8	4.2	0.0	0.0
Concord	288	70	79	29.73	30.04	-.01	55.0	+6.3	81	21	67	32	24	43	40	....	....	....	0.98	-2.3	5	3,213	nw.	24	nw.	22	14	6	11	5.0	0.0	0.0
Burlington	404	11	48	29.60	30.04	.00	52.8	+5.9	73	21	62	33	13	44	31	....	....	....	1.76	-1.4	10	7,470	s.	42	sw.	27	9	7	15	6.4	T.	0.0
Northfield	876	12	60	29.11	30.06	+.02	51.3	+7.7	77	21	64	26	13	39	43	46	43	82	1.80	-0.7	8	4,528	s.	27	n.	22	11	7	13	5.8	T.	0.0
Boston	125	115	188	29.92	30.05	.00	59.8	+7.5	82	21	68	37	30	51	30	52	47	67	1.64	-2.2	3	6,863	w.	38	s.	1	12	15	4	4.5	0.0	0.0
Nantucket	12	14	90	30.04	30.05	.00	58.5	+4.0	76	9	65	41	30	52	24	55	52	83	3.96	+0.6	5	10,759	sw.	42	sw.	29	13	11	7	4.1	0.0	0.0
Block Island	26	11	46	30.04	30.07	+.02	58.6	+3.3	74	14	64	43	30	53	19	54	52	82	1.48	-2.6	2	11,128	sw.	46	w.	30	17	6	8	3.9	0.0	0.0
Providence	160	215	251	29.88	30.06	+.01	58.6	+6.4	81	21	68	36	30	49	28	53	50	77	1.44	-2.4	5	8,110	nw.	52	s.	1	17	8	6	3.7	0.0	0.0
Hartford	159	122	140	29.89	30.07	+.01	58.2	+7.0	82	21	69	37	13	48	35	51	47	73	0.90	-3.0	6	4,846	sw.	54	s.	1	16	8	7	4.1	0.0	0.0
New Haven	106	74	153	29.97	30.08	+.02	58.6	+4.8	82	14	68	36	30	50	31	52	48	75	0.79	-3.1	3	6,040	n.	41	s.	1	16	10	5	3.5	0.0	0.0
Middle Atlantic States.							60.3	+4.6										76	0.82	-2.4										3.5		
Albany	97	102	115	29.96	30.07	+.01	57.6	+7.2	81	14	67	37	24	48	32	51	48	79	1.53	-1.5	8	4,623	s.	30	s.	27	15	8	8	4.2	T.	0.0
Binghamton	871	10	84	29.16	30.09	+.03	57.0	+7.8	81	15	68	34	30	45	36	....	....	....	1.45	-1.7	9	3,388	w.	24	nw.	5	13	10	8	4.8	T.	0.0
New York	314	414	454	29.75	30.08	+.02	60.4	+4.8	82	14	68	37	30	52	24	53	48	69	0.77	-2.9	5	11,086	nw.	55	nw.	5	15	9	7	4.2	0.0	0.0
Harrisburg	374	94	104	29.73	30.13	+.05	59.8	+5.8	82	14	70	39	3	50	30	52	48	72	0.52	-2.4	3	3,808	w.	28	sw.	27	17	8	6	3.6	0.0	0.0
Philadelphia	117	123	190	29.99	30.12	+.05	62.4	+6.1	85	15	71	41	31	54	27	56	52	76	0.64	-2.5	3	6,197	sw.	30	nw.	5	17	7	7	3.7	0.0	0.0
Reading	325	81	98	29.76	30.12	......	60.3	......	83	15	71	39	30	50	34	52	47	70	0.82	-2.4	2	3,682	nw.	25	n.	5	16	7	8	3.9	0.0	0.0
Scranton	805	111	119	29.25	30.11	+.04	57.5	+6.1	81	21	68	35	7	46	35	50	47	79	2.02	-0.9	7	4,392	n.	26	sw.	4	15	11	5	4.3	0.0	0.0
Atlantic City	52	37	48	30.05	30.11	+.04	60.2	+2.8	8.	22	68	38	30	53	28	55	52	78	0.67	-2.6	3	5,016	w.	25	s.	27	20	6	5	3.0	0.0	0.0
Cape May	18	13	49	30.12	30.14	+.07	62.2	+2.6	83	22	69	44	7	55	22	55	52	79	1.47	-1.8	4	5,598	w.	28	nw.	5	20	6	5	2.6	0.0	0.0
Sandy Hook	22	10	57	30.07	30.09	......	59.8	......	78	14	67	40	30	53	22	55	52	82	0.83	......	4	9,986	sw.	44	s.	27	15	11	5	4.3	0.0	0.0
Trenton	190	159	183	29.89	30.09	......	59.6	......	83	15	70	36	30	50	29	53	49	74	0.92	-2.5	5	7,037	w.	33	s.	27	17	7	7	3.8	0.0	0.0
Baltimore	123	100	113	30.00	30.13	+.05	63.1	+5.6	85	22	73	39	30	53	28	55	50	69	0.17	-2.8	1	3,803	sw.	19	w.	29	18	8	5	3.3	0.0	0.0
Washington	112	62	85	30.01	30.13	+.05	61.2	+4.6	85	15	73	38	31	50	33	53	49	76	0.40	-2.7	4	3,675	nw.	28	nw.	29	18	8	5	3.5	0.0	0.0
Lynchburg	681	153	188	29.41	30.16	+.07	60.8	+3.9	86	22	74	34	30	48	38	52	49	76	0.10	-3.3	1	4,173	nw.	26	nw.	29	24	5	2	2.0	0.0	0.0
Norfolk	91	170	205	30.04	30.14	+.07	64.6	+3.3	85	15	73	40	30	56	28	57	53	74	0.94	-3.0	4	8,008	w.	35	s.	27	22	5	4	2.9	0.0	0.0
Richmond	144	11	52	29.99	30.15	+.06	62.0	+2.2	86	22	74	34	31	50	34	55	52	80	0.66	-2.7	2	4,531	sw.	25	s.	27	21	2	8	3.3	0.0	0.0
Wytheville	2,304	49	56	27.81	30.21	+.12	55.4	+1.8	79	22	69	27	30	42	39	47	44	78	0.08	-3.1	1	3,398	w.	24	w.	1	27	4	0	1.4	T.	0.0
South Atlantic States.							64.7	+1.0										74	0.58	-3.1										3.1		
Asheville	2,255	70	84	27.85	30.22	+.13	56.4	+1.1	80	11	69	27	30	44	36	48	45	75	0.47	-2.5	3	4,318	nw.	27	se.	27	20	6	5	3.0	0.0	0.0
Charlotte	779	55	62	29.33	30.17	+.09	62.7	+1.6	84	11	74	32	30	51	31	53	48	66	0.10	-3.0	1	2,676	ne.	17	nw.	1	20	7	4	2.7	0.0	0.0
Hatteras	11	12	50	30.11	30.12	+.06	66.2	+0.2	79	16	72	48	30	61	18	62	59	81	0.32	-5.7	3	9,595	ne.	38	n.	9	17	9	5	3.6	0.0	0.0
Manteo	12	5	42																													
Raleigh	376	103	110	29.75	30.15	+.08	63.6	+3.1	85	22	74	35	30	53	28	55	50	66	2.29	-1.2	3	4,828	ne.	24	sw.	27	18	4	9	3.5	0.0	0.0
Wilmington	78	81	91	30.07	30.15	+.09	65.0	+1.7	85	13	76	36	30	55	28	58	55	78	0.48	-3.3	2	4,083	n.	26	sw.	27	18	10	3	3.2	0.0	0.0
Charleston	48	11	92	30.09	30.14	+.08	67.5	+0.4	84	15	76	45	30	59	26	60	56	74	0.06	-3.9	3	6,805	n.	29	sw.	27	18	11	2	2.9	0.0	0.0
Columbia, S. C.	351	41	57	29.79	30.18	+.11	64.8	+0.8	86	13	76	36	30	55	33	56	52	72	0.58	-2.3	2	3,764	n.	27	sw.	27	21	6	4	2.8	0.0	0.0
Greenville, S. C.	1,039	113	122	29.06	30.16	......	63.0	......	84	10	74	36	29	52	33	54	48	65	0.53	......	2	4,664	ne.	22	sw.	27	20	7	4	3.0	0.0	0.0
Augusta	180	62	77	29.96	30.15	+.08	64.6	+1.0	87	17	77	38	30	52	35	57	54	79	1.01	-1.3	3	2,977	nw.	18	nw.	1	20	4	7	3.0	0.0	0.0
Savannah	65	150	194	30.08	30.14	+.09	67.0	+0.7	86	10	76	43	30	58	27	59	55	75	0.43	-3.1	2	6,925	ne.	30	sw.	27	18	7	6	3.3	0.0	0.0
Jacksonville	43	209	245	30.07	30.12	+.10	68.8	-0.8	82	27	76	45	29	62	21	62	59	79	0.11	-5.0	5	9,493	ne.	35	ne.	7	17	12	2	3.1	0.0	0.0
Florida Peninsula.							75.0	-1.8										75	2.47	-3.8										5.0		
Key West	22	10	64	29.96	29.98	+.04	77.6	-1.1	87	5	82	67	1	73	12	71	69	78	2.25	-3.1	11	8,580	ne.	31	ne.	18	13	11	7	5.0	0.0	0.0
Miami	25	71	79	29.99	30.02		75.2	-2.6	83	6	80	59	1	70	20	69	67	75	5.04	-5.5	15	7,433	e.	31	e.	20	5	15	11	6.3	0.0	0.0
Sand Key	23	39	72																													
Tampa	35	79	92	30.03	30.07	+.09	72.2	-1.6	87	11	81	50	29	63	25	64	60	73	0.12	-2.8	2	6,163	ne.	24	ne.	21	16	10	5	3.8	0.0	0.0
East Gulf States.							66.6	+1.0										71	1.51	-1.3										3.5		
Atlanta	1,174	190	216	28.93	30.17	+.10	64.7	+2.3	84	17	74	37	29	55	27	54	48	60	0.54	-1.8	1	6,403	e.	33	nw.	28	23	2	6	3.0	0.0	0.0
Leesburg	279	10	55																													
Macon	370	78	87	29.76	30.16	+.10	63.6	-0.1	87	10	76	34	30	51	41	55	51	72	0.45	-1.7	2	3,630	n.	21	nw.	28	19	5	7	3.3	0.0	0.0
Thomasville	273	49	58	29.83	30.12	+.08	67.1	-1.1	86	11	78	40	29	56	31	58	53	71	1.23	-2.2	3	3,005	ne.	20	sw.	27	18	6	7	3.4	0.0	0.0
Pensacola	56	149	185	30.05	30.11	+.08	69.0	-0.4	82	12	76	46	1	62	21	62	58	72	2.27	-1.8	4	9,111	e.	36	se.	24	13	10	8	4.3	0.0	0.0
Anniston	741	9	57	29.39	30.19	+.12	62.7	+0.3	87	12	77	29	30	48	43	....	....	....	0.73	-1.6	3	2,966	se.	16	nw.	27	22	3	6	2.7	0.0	0.0
Birmingham	700	11	48	29.40	30.16	+.09	66.4	+2.0	88	16	78	36	30	54	39	54	47	61	0.54	-1.8	3	4,133	se.	22	se.	24	18	9	4	3.2	0.0	0.0
Mobile	57	125	161	30.05	30.11	+.07	68.8	+1.7	87	12	78	45	29	59	31	62	58	76	4.65	+1.5	4	6,020	n.	28	sw.	24	17	7	7	3.6	0.0	0.0
Montgomery	223	100	112	29.89	30.15	+.09	66.6	+0.9	88	12	78	37	30	55	36	56	49	62	1.17	-1.3	3	3,891	se.	19	s.	26	19	7	5	3.1	0.0	0.0
Corinth	469	6																														
Meridian	375	85	93	29.72	30.12	+.06	64.8	+1.8	86	11	78	36	29	52	39	56	52	74	0.79	-1.9	4	2,978	e.	18	sw.	26	17	9	5	3.1	0.0	0.0
Vicksburg	247	65	74	29.84	30.12	+.06	67.4	+2.1	86	21	77	43	28	57	26	59	56	77	0.60	-2.2	5	4,418	se.	18	se.	15	15	9	7	4.1	0.0	0.0
New Orleans	53	76	84	30.03	30.08	+.05	71.4	+1.9	85	13	79	54	29	64	21	65	64	84	3.59	+0.7	5	4,706	se.	22	s.	24	11	9	11	4.9	0.0	0.0
West Gulf States.							68.1	+1.5										77	5.61	+2.8										4.8		
Shreveport	249	77	93	29.82	30.09	+.04	66.9	+1.3	85	5	76	40	28	57	29	59	55	76	2.89	-0.3	9	4,746	se.	24	se.	14	16	7	8	4.0	0.0	0.0
Bentonville	1,303	11	44	28.70	30.07	+.02	61.4	+3.4	82	4	71	34	28	51	33	....	....	....	5.00	+2.2	9	4,104	s.	22	s.	13	17	4	10	4.3	0.0	0.0
Fort Smith	457	79	94	29.57	30.05	.00	64.8	+3.1	88	4	74	36	28	55	33	57	53	75	4.74	+1.9	8	5,854	e.	24	se.	14	14	5	12	4.9	0.0	0.0
Little Rock	357	139	147	29.72	30.09	+.03	65.4	+2.5	84	4	75	37	28	56	32	58	55	76	3.23	+0.7	7	5,329	s.	26	nw.	27	14	7	10	4.5	0.0	0.0
Brownsville	57	4	26	......	......	......	75.8	......	94	15	87	50	28	65	34	....	....	....	3.56	......	8	......	n.	....		....	....	....	....	....	0.0	0.0
Corpus Christi	20	69	*77	30.00	30.02	+.02	73.7	+1.1	87	6	79	56	28	68	23	68	65	78	7.31	+5.3	11	9,062	e.	36	se.	14	13	7	11	5.3	0.0	0.0
Dallas	512	109	117	29.50	30.04	......	67.3	......	87	5	77	42	28	58	28	....	....	....	3.78	......	9	6,587	se.	30	s.	13	11	9	11	5.3	0.0	0.0
Fort Worth	670	106	114	29.31	30.02	-.01	67.6	+1.3	87	5	77	40	28	58	31	59	56	75	6.52	+4.0	9	7,729	se.	30	s.	13	11	12	8	4.8	0.0	0.0
Galveston	54	106	114	30.01	30.07	+.04	72.3	-0.1	84	6	77	52	28	68	16	66	63	77	7.92	+3.7	9	8,797	se.	36	n.	22	13	9	9	4.5	0.0	0.0
Groesbeck	461	11	56	29.54	30.03	......	67.4	......	89	14	78	37	28	57	35	60	58	83	4.99	......	8	6,778	se.	39	se.	21	13	5	13	4.8	0.0	0.0
Houston	138	111	121	29.90	30.04	......	70.4	+0.5	86	13	79	46	28	62	26	....	....	....	9.04	......	9	6,385	se.	29	se.	14	16	10	5	3.9	0.0	0.0
Palestine	510	64	72	29.53	30.07	+.04	67.1	+0.9	86	14	76	40	28	58	31	60	56	78	5.80	+2.2	11	5,240	se.	26	se.	14	13	2	16	5.6	0.0	0.0
Port Arthur	34	58	66	30.01	30.05	......	69.8	......	83	6	76	45	28	63	25	64	61	82	5.37	......	10	6,984	e.	47	e.	22	15	7	9	4.9	0.0	0.0
San Antonio	701	119	132	29.30	30.02	+.01	71.0	+1.8	89	15	81	44	28	61	31	62	58	73	2.85	+1.4	9	5,831	n.	32	se.	19	12	12	9	4.6	0.0	0.0
Taylor	582	55	63	29.45	30.06	+.04	68.6	+0.3	90	14	79	39	28	58	32	....	....	....	9.83	+7.3	9	5,733	se.	26	s.	14	7	10	12	5.7	0.0	0.0

TABLE I.—*Climatological data for Weather Bureau Stations, October, 1920*—Continued.

Districts and stations.	Elevation of instruments.			Pressure.			Temperature of the air.									Mean wet thermometer.	Mean temperature of the dew-point.	Mean relative humidity.	Precipitation.			Wind.					Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow on ground at end of month.
	Barometer above sea level.	Thermometer above ground.	Anemometer above ground.	Station, reduced to mean of 24 hours.	Sea level, reduced to mean of 24 hours.	Departure from normal.	Mean max.+mean min.÷2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.				Total.	Departure from normal.	Days with 0.01 inch or more.	Total movement.	Prevailing direction.	Maximum velocity: Miles per hour.	Maximum velocity: Direction.	Maximum velocity: Date.						
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles.								0–10	In.	In.
Ohio Valley and Tennessee.							61.2	+ 5.0										70	1.70	− 0.8										3.7		
Chattanooga	762	189	213	29.37	30.19	+ .10	62.0	+ 1.2	82	12	74	34	30	50	35	53	48	70	0.74	− 2.1	3	3,309	n.	27	sw.	27	18	8	5	3.4	0.0	0.0
Knoxville	996	102	111	29.13	30.19	+ .10	60.4	+ 2.3	83	23	73	23	31	47	35	52	48	73	0.78	− 1.8	2	2,792	ne.	32	sw.	27	16	7	8	3.7	0.0	0.0
Memphis	399	76	97	29.73	30.15	+ .08	66.5	+ 4.0	84	21	75	38	29	58	27	57	51	65	2.68	− 0.1	5	5,202	se.	30	sw.	15	19	4	8	3.5	0.0	0.0
Nashville	546	168	191	29.59	30.18	+ .10	62.6	+ 2.3	84	13	75	32	29	50	37	53	47	67	2.75	+ 0.3	3	5,030	s.	34	s.	15	19	7	5	3.3	0.0	0.0
Lexington	989	193	230	29.11	30.17	+ .09	62.1	+ 5.6	84	22	71	30	29	53	24	......	......	......	2.75	+ 0.5	7	8,991	sw.	40	sw.	27	19	7	5	3.2	T.	0.0
Louisville	525	219	255	29.58	30.16	+ .08	63.0	+ 4.6	86	23	74	32	30	52	34	53	47	62	1.55	− 1.1	4	6,646	s.	37	s.	15	20	6	5	2.9	0.0	0.0
Evansville	431	139	175	29.68	30.14	+ .06	64.2	+ 6.2	85	18	75	33	29	53	30	54	48	64	1.65	− 1.4	5	6,722	sw.	36	s.	15	17	10	4	3.7	T.	0.0
Indianapolis	822	194	230	29.24	30.13	+ .06	61.6	+ 6.6	82	22	72	33	29	52	28	52	46	64	1.96	− 0.8	4	7,493	s.	38	sw.	15	16	5	10	4.0	T.	0.0
Royal Center	736	11	55	29.32	30.12	......	59.3	......	84	11	71	27	30	48	35	51	47	74	1.90	......	6	6,297	s.	32	s.	15	17	6	8	4.2	T.	0.0
Terre Haute	575	96	129	29.48	30.10	......	61.9	......	83	21	73	31	29	51	33	52	46	65	1.30	......	4	6,430	s.	42	s.	15	14	11	6	4.1	T.	0.0
Cincinnati	628	11	51	29.48	30.16	+ .08	60.2	+ 7.2	84	19	72	31	30	48	39	......	......	......	1.76	− 0.6	3	4,142	sw.	30	sw.	27	17	8	6	3.4	0.0	0.0
Columbus	824	179	222	29.28	30.16	+ .08	59.8	+ 5.7	82	21	70	31	30	49	32	52	49	74	1.61	− 0.7	4	6,997	sw.	38	w.	27	18	5	8	3.3	T.	0.0
Dayton	899	181	216	29.16	30.11	......	60.7	+ 6.6	82	22	72	31	30	50	32	51	45	66	1.61	− 0.8	4	6,285	sw.	50	s.	26	19	5	7	3.6	T.	0.0
Elkins	1,947	59	67	28.13	30.22	+ .14	53.7	+ 8.4	82	24	68	24	31	39	42	45	44	87	1.07	− 1.4	5	2,415	w.	20	w.	27	16	9	6	4.0	0.3	0.0
Parkersburg	638	77	84	29.52	30.18	+ .10	59.8	+ 5.2	84	21	72	32	31	47	36	51	47	76	1.40	− 1.0	6	2,836	se.	20	s.	27	19	6	6	3.8	T.	0.0
Pittsburgh	842	353	410	29.24	30.15	+ .07	59.6	+ 4.7	81	21	70	34	29	50	30	51	46	70	1.48	− 0.9	6	6,510	sw.	31	nw.	29	14	6	11	4.5	T.	0.0
Lower Lake Region.							58.1	+ 6.3										72	2.22	− 0.8										5.1		
Buffalo	767	247	280	29.25	30.09	+ .04	57.2	+ 5.7	76	15	63	34	29	51	20	52	48	75	1.77	− 1.8	11	12,032	sw.	66	sw.	27	6	9	16	6.8	T.	0.0
Canton	448	10	61	29.55	30.02	......	52.8	+ 5.6	74	14	62	31	13	44	38	......	......	......	1.68	− 1.7	15	7,039	sw.	39	sw.	27	11	6	14	5.9	T.	0.0
Oswego	335	76	91	29.69	30.06	+ .01	55.6	+ 4.4	77	15	63	35	29	48	30	51	47	77	1.61	− 1.7	10	6,790	s.	36	ne.	1	11	7	13	5.3	T.	0.0
Rochester	523	86	102	29.51	30.09	+ .04	57.4	+ 6.6	82	15	66	33	30	49	29	50	46	73	1.24	− 1.6	10	5,779	sw.	26	w.	30	9	9	13	5.7	T.	0.0
Syracuse	597	97	113	29.43	30.08	+ .02	57.4	+ 6.4	79	21	65	32	30	49	28	......	......	......	0.68	− 2.5	9	7,083	s.	34	s.	27	9	9	13	5.6	T.	0.0
Erie	714	130	166	29.32	30.10	+ .05	58.8	+ 5.7	82	15	66	38	29	52	25	52	47	71	4.67	+ 0.9	7	9,463	sw.	38	sw.	27	9	15	7	5.1	0.2	0.0
Cleveland	762	190	201	29.29	30.12	+ .06	59.5	+ 6.4	81	14	67	37	29	52	25	52	47	69	2.57	− 0.2	7	8,948	s.	48	sw.	27	12	12	7	4.8	T.	0.0
Sandusky	629	62	103	29.43	30.12	+ .06	60.3	+ 6.4	83	14	69	34	30	52	28	......	......	......	3.30	+ 0.9	5	8,371	sw.	44	sw.	27	15	7	9	4.5	T.	0.0
Toledo	628	208	243	29.43	30.12	+ .07	60.6	+ 8.0	83	22	70	32	29	51	27	52	46	67	2.39	+ 0.1	7	9,222	sw.	48	sw.	27	18	6	7	3.6	T.	0.0
Fort Wayne	856	113	124	29.20	30.13	......	59.8	+ 6.1	83	11	70	30	30	49	32	51	46	68	2.22	......	7	6,085	sw.	30	s.	15	16	7	8	4.3	T.	0.0
Detroit	730	218	245	29.31	30.11	+ .06	59.4	+ 7.7	81	21	68	32	29	51	24	52	48	74	2.26	− 0.1	9	7,540	sw.	45	sw.	27	11	11	9	4.8	0.0	0.0
Upper Lake Region.							56.0	+ 8.3										77	1.85	− 1.0										5.2		
Alpena	609	13	92	29.39	30.06	+ .03	53.9	+ 8.0	82	20	62	31	29	46	32	49	47	84	1.65	− 1.8	8	7,231	sw.	32	nw.	1	5	13	13	6.4	0.9	0.0
Escanaba	612	54	60	29.38	30.04	+ .03	53.2	+ 8.1	76	21	60	28	30	46	27	48	46	83	0.33	− 2.8	7	6,230	s.	31	n.	27	16	7	8	3.9	T.	0.0
Grand Haven	632	54	89	29.38	30.07	+ .04	56.8	+ 6.6	80	15	64	34	29	49	33	52	49	79	1.50	− 1.0	7	7,453	s.	29	nw.	27	11	10	10	5.2	T.	0.0
Grand Rapids	707	70	87	29.32	30.09	+ .05	58.8	+ 8.7	82	15	68	32	30	50	31	51	47	73	1.82	− 0.7	8	3,039	s.	23	w.	15	10	10	11	5.5	T.	0.0
Houghton	684	62	99	29.29	30.02	+ .02	54.2	+ 9.1	81	7	62	26	29	46	30	......	......	......	2.50	− 0.7	12	6,404	e.	41	sw.	13	13	9	9	4.8	0.6	0.0
Lansing	878	11	62	29.14	30.09	......	57.8	+ 9.1	82	22	70	28	30	46	35	49	46	78	1.37	− 0.9	10	3,553	sw.	19	s.	15	10	9	12	5.5	T.	0.0
Ludington	637	60	66	29.36	30.06	......	56.3	......	76	15	62	33	28	50	23	51	48	78	2.44	......	11	7,353	s.	28	nw.	27	14	9	8	4.2	T.	0.0
Marquette	734	77	111	29.24	30.05	+ .04	56.0	+10.3	79	8	64	28	29	48	25	49	46	77	1.82	− 1.4	9	7,187	s.	36	sw.	7	11	7	13	5.8	1.4	0.0
Port Huron	638	70	120	29.88	30.08	+ .04	56.9	+ 7.4	81	21	65	29	30	49	28	51	48	81	2.77	0.0	9	7,217	sw.	32	n.	1	13	7	11	5.2	T.	0.0
Saginaw	641	69	77	29.39	30.08	......	57.4	......	81	14	67	28	30	48	30	50	47	78	2.01	− 0.8	9	5,275	sw.	26	s.	15	10	10	11	5.5	0.0	0.0
Sault Saint Marie	614	11	52	29.35	30.05	+ .04	51.8	+ 8.4	76	20	60	23	29	43	30	47	44	82	0.18	− 3.1	5	5,329	se.	28	nw.	1	5	10	16	6.8	0.4	0.0
Chicago	823	140	310	29.20	30.09	+ .05	61.9	+ 8.7	82	10	69	31	29	55	27	53	48	66	1.57	− 1.0	8	8,219	sw.	40	s.	15	19	5	7	4.0	0.2	0.0
Green Bay	617	109	144	29.38	30.04	+ .02	56.2	+ 8.1	80	22	65	25	29	47	30	49	45	74	2.27	− 0.1	9	8,057	s.	35	n.	28	13	8	10	5.4	T.	0.0
Milwaukee	681	125	139	29.32	30.06	+ .03	58.4	+ 8.2	81	21	66	28	29	51	28	51	46	72	1.99	− 0.4	8	6,408	sw.	28	n.	28	15	3	13	4.9	T.	0.0
Duluth	1,133	11	47	28.77	30.00	.00	51.8	+ 6.6	78	7	60	19	28	44	28	45	41	76	4.10	+ 1.4	9	9,108	ne.	37	w.	13	15	3	13	5.0	0.1	0.0
North Dakota.							49.6	+ 7.1										68	0.61	− 0.6										4.8		
Moorhead	940	8	57	28.94	29.96	− .04	51.3	+ 8.5	89	6	63	18	28	40	40	44	39	72	1.03	− 1.0	6	6,385	s.	26	s.	6	8	11	12	5.6	T.	0.0
Bismarck	1,674	8	57	28.16	29.96	− .03	50.6	+ 6.5	91	6	64	17	31	37	44	42	35	64	0.26	− 0.8	3	6,989	nw.	35	s.	22	15	7	9	4.2	T.	0.0
Devils Lake	1,482	11	44	28.32	29.91	− .08	48.9	+ 8.4	89	6	61	20	28	36	42	41	35	70	0.23	− 1.0	4	7,664	se.	48	sw.	8	18	4	9	4.1	T.	0.0
Ellendale	1,457	10	56	28.38	29.95	......	50.9	......	89	6	64	16	28	37	43	43	38	73	0.81	......	5	10,747	s.	48	sw.	22	10	12	9	5.1	T.	0.0
Grand Forks	835	12	89	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Williston	1,878	41	48	27.92	29.91	− .07	47.8	+ 4.9	86	5	60	24	31	36	44	39	33	62	0.92	+ 0.2	6	6,119	w.	38	w.	8	11	13	7	4.8	0.0	0.0
Upper Mississippi Valley.							59.7	+ 6.9										72	2.18	− 0.2										4.4		
Minneapolis	918	102	208	28.98	29.96	......	56.4	......	79	7	66	26	28	47	30	......	......	......	2.79	+ 0.2	11	8,215	s.	37	s.	12	13	6	12	5.0	T.	0.0
St. Paul	837	236	261	29.10	30.00	− .01	55.6	+ 7.5	77	7	65	23	29	46	29	......	......	......	1.85	− 0.5	10	8,407	se.	45	s.	13	15	9	7	4.2	T.	0.0
La Crosse	714	11	48	29.26	30.04	+ .02	56.9	+ 7.0	81	21	69	21	29	45	37	......	......	......	2.56	+ 0.1	10	3,375	s.	24	s.	12	15	7	9	4.5	0.8	0.0
Madison	974	70	78	29.02	30.07	+ .04	57.4	+ 8.6	82	10	66	26	29	48	30	50	46	73	1.90	− 0.5	7	6,024	s.	27	s.	19	13	7	11	5.0	T.	0.0
Wausau	1,247	4	....	28.71	30.04	......	53.8	......	77	22	64	18	29	43	39	......	......	......	3.17	......	9	......	se.			....	11	8	12	5.5	T.	0.0
Charles City	1,015	10	49	28.96	30.04	+ .02	55.8	+ 7.6	83	11	67	22	29	45	38	48	45	80	4.64	+ 2.6	8	4,372	s.	32	sw.	20	14	8	9	4.7	T.	0.0
Davenport	606	71	79	29.41	30.07	+ .03	60.4	+ 7.8	84	10	69	26	29	51	29	52	48	71	2.40	0.0	10	4,319	sw.	24	s.	13	14	8	9	4.4	0.0	0.0
Des Moines	861	84	97	29.11	30.02	− .01	60.2	+ 7.7	86	10	70	25	29	50	33	51	45	67	1.89	− 0.8	7	5,009	s.	28	s.	13	17	8	6	3.8	0.0	0.0
Dubuque	698	81	96	29.33	30.08	+ .04	58.6	+ 6.6	85	11	69	24	29	49	35	51	47	74	2.18	− 0.5	8	3,734	s.	22	n.	27	16	6	9	4.3	0.1	0.0
Keokuk	614	64	78	29.40	30.08	+ .03	61.6	+ 7.1	84	10	70	27	29	53	29	53	48	68	1.00	− 1.5	11	4,986	s.	24	sw.	15	15	6	10	4.4	T.	0.0
Cairo	356	87	93	29.73	30.12	+ .05	63.9	+ 4.8	84	21	74	32	29	54	28	55	50	71	2.09	− 0.5	4	4,947	s.	33	n.	28	15	4	12	4.7	0.0	0.0
Peoria	609	11	45	29.43	30.10	+ .05	60.2	+ 8.2	86	10	71	24	29	49	35	51	47	75	1.93	− 0.6	9	4,041	s.	26	sw.	15	17	3	11	4.2	T.	0.0
Springfield, Ill	644	10	91	29.40	30.08	+ .03	60.6	+ 6.0	82	11	70	30	29	51	30	52	48	73	1.49	− 1.1	8	5,576	s.	24	s.	15	16	5	10	4.2	T.	0.0
Hannibal	534	74	109	29.51	30.08	+ .03	61.4	+ 5.5	83	10	71	26	29	52	35	......	......	......	1.48	− 0.2	12	5,948	s.	33	sw.	15	16	5	10	4.2	0.1	0.0
St. Louis	567	265	303	29.48	30.09	+ .03	64.0	+ 5.6	85	10	73	35	29	55	28	54	48	64	2.36	0.0	9	9,693	s.	44	sw.	15	17	9	5	3.5	T.	0.0
Missouri Valley.							59.0	+ 6.3										68	2.38	+ 0.5										3.8		
Columbia, Mo	781	11	84	29.24	30.07	+ .02	61.6	+ 6.8	83	10	71	25	29	52	34	......	......	......	2.67	+ 0.2	13	5,359	s.	28	sw.	15	18	3	10	4.0	0.0	0.0
Kansas City	963	161	181	29.00	30.04	.00	62.4	+ 6.6	86	10	70	33	29	54	26	54	48	67	1.87	− 0.3	7	9,116	s.	35	n.	26	17	5	9	3.9	0.0	0.0
St. Joseph	967	11	49	28.99	30.02	......	61.4	......	88	10	71	27	29	51	33	53	48	70	2.22	......	5	5,906	s.	26	nw.	27	18	6	7	3.8	0.0	0.0
Springfield, Mo	1,324	98	104	28.68	30.08	+ .03	61.2	+ 3.9	82	4	70	33	29	53	28	54	50	75	4.09	+ 1.3	10	8,017	se.	31	s.	14	20	3	8	3.5	0.0	0.0
Iola	984	11	50	28.98	30.02	− .02	61.9	+ 5.0	88	4	72	31	29	51	34	......	......	......	4.09	+ 1.8	9	5,150	s.	23	ne.	24	14	6	11	4.7	0.0	0.0
Topeka	987	92	107	......	......	......	60.9	+ 4.6	88	10	71	28	29	51	32	......	......	......	2.19	+ 0.3	6	8,193	s.	37	s.	13	13	9	9	4.5	0.0	0.0
Drexel	1,299	10	53	28.59	29.98	......	58.9	......	86	10	70	25	29	48	36	49	44	70	4.94	......	4	7,697	s.	41	sw.	13	18	7	6	3.4	0.0	0.0
Lincoln	1,189	11	84	28.71	29.97	− .06	60.6	+ 7.3	89	10	72	26	29	49	41	51	45	65	2.98	+ 1.2	4	6,908	s.	33	w.	11	18	8	5	3.6	0.0	0.0
Omaha	1,105	115	122	28.82	30.00	− .03	61.0	+ 6.8	88	10	71	31	29	51	34	51	45	65	2.87	+ 0.5	4	5,195	s.	30	nw.	26	18	7	6	3.4	0.0	0.0
Valentine	2,598	47	54	27.25	29.97	− .04	53.4	+ 4.9	87	9	67	18	28	40	43	43	36	63	1.21	− 0.1	5	7,360	s.	41	sw.	22	20	7	4	3.0	5.5	5.5
Sioux City	1,135	94	164	28.78	29.99	− .03	57.6	+ 6.5	83	10	68	24	28	47	38	49	43	66	2.36	+ 0.6	5	8,918	s.	36	s.	13	17	8	6	3.5	0.0	0.0
Huron	1,306	59	74	28.57	29.98	......	54.6	+ 9.9	88	6	67	20	28	42	39	45	40	67	0.52	− 0.8	4	8,069	se.	32	s.	18	21	4	6	2.9	T.	T.
Pierre	1,572	70	75	28.27	29.93	− .08	55.2	+ 6.1	93	6	68	22	28	43	45	47	43	72	1.25	+ 0.4	6	6,380	nw.	41	ne.	13	16	8	7	4.3	0.6	0.3
Yankton	1,233	49	57	28.65	29.97	− .04	57.5	+ 7.0	84	10	69	19	28	46	44	......	......	......	2.46	+ 0.9	6	5,944	s.	30	sw.	11	14	12	5	4.1	0.0	0.0

TABLE I.—*Climatological data for Weather Bureau Stations, October, 1920*—Continued.

Districts and stations.	Elevation of instruments. Barometer above sea level.	Thermometer above ground.	Anemometer above ground.	Pressure. Station, reduced to mean of 24 hours.	Sea level, reduced to mean of 24 hours.	Departure from normal.	Temperature of the air. Mean max.+mean min.÷2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.	Mean wet thermometer.	Mean temperature of the dew-point.	Mean relative humidity.	Precipitation. Total.	Departure from normal.	Days with 0.01 inch or more.	Wind. Total movement.	Prevailing direction.	Maximum velocity. Miles per hour.	Direction.	Date.	Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow on ground at end of month.
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles.								0–10	In.	In.
Northern Slope.							46.3	+ 1.6										63	1.64	+ 0.7										5.3		
Billings	3,140	5	......	......	......	......	50.8	......	95	5	65	20	31	37	50	......	......	......	0.23	......	4	......	w.	......	......	......	13	12	6	......	2.0	2.0
Havre	2,505	11	44	27.29	29.94	− .04	46.7	+ 3.1	89	5	58	22	27	36	51	39	34	70	1.25	+ 0.8	5	6,220	sw.	44	sw.	14	11	10	10	5.3	T.	0.0
Helena	4,110	87	112	25.77	30.00	− .03	43.2	− 0.8	81	4	53	17	31	34	42	36	30	65	2.01	+ 1.2	11	5,379	sw.	40	sw.	7	2	10	19	7.7	2.5	0.0
Kalispell	2,973	48	56	......	29.98	− .03	42.4	− 0.1	68	6	51	21	31	34	28	......	......	......	1.25	+ 0.1	13	3,424	nw.	25	sw.	1	7	9	15	......	T.	0.0
Miles City	2,371	26	48	27.43	30.00	.00	51.4	+ 4.9	91	5	64	25	27	39	47	42	37	69	0.34	− 0.4	4	4,525	se.	45	w.	1	14	14	3	4.1	0.3	T.
Rapid City	3,259	50	58	26.57	29.99	− .02	50.8	+ 4.2	89	5	63	19	31	38	49	40	31	53	1.38	+ 0.3	6	5,829	w.	34	nw.	11	11	12	8	5.0	5.6	5.6
Cheyenne	6,088	84	101	23.98	29.96	− .05	46.0	+ 0.7	75	5	58	17	31	34	35	36	28	56	0.96	+ 0.2	5	8,480	w.	55	w.	10	8	11	12	5.5	7.3	4.0
Lander	5,372	60	68	24.63	30.02	− .02	42.4	+ 0.3	77	5	55	17	23	30	42	34	26	60	4.45	+ 3.4	10	3,442	sw.	39	w.	1	8	13	10	5.6	34.5	27.2
Sheridan	3,790	10	47	26.07	30.00	......	44.5	......	90	5	58	16	27	30	55	36	28	61	1.19	......	6	3,941	nw.	39	nw.	22	12	4	15	5.5	5.3	5.3
Yellowstone Park	6,200	11	48	23.86	30.04	+ .02	38.2	− 3.3	73	4	48	10	23	28	37	32	27	70	1.80	+ 0.7	16	6,152	s.	42	sw.	7	8	10	13	5.8	17.1	4.3
North Platte	2,821	11	51	27.06	29.99	− .03	55.3	+ 5.3	87	6	70	17	28	41	48	43	36	61	1.29	+ 0.1	5	5,713	s.	29	ne.	31	20	7	4	2.9	0.5	0.5
Middle Slope.							58.8	+ 3.3										65	2.85	+ 1.3										3.9		
Denver	5,292	106	113	24.70	29.95	− .06	52.2	+ 1.2	83	5	64	20	31	40	36	40	30	52	0.87	− 0.1	7	5,407	s.	30	nw.	11	14	8	9	4.8	4.7	3.5
Pueblo	4,685	80	86	25.26	29.94	− .05	53.2	+ 0.9	84	10	68	24	28	38	45	41	30	51	0.91	+ 0.2	5	4,481	nw.	29	w.	11	17	9	5	3.5	0.3	0.0
Concordia	1,392	50	58	28.53	30.00	− .03	60.8	+ 5.4	92	10	73	28	29	49	41	51	44	65	1.61	− 0.4	7	6,682	s.	34	s.	13	16	8	7	3.9	0.0	0.0
Dodge City	2,509	11	51	27.40	29.99	− .03	59.8	+ 5.1	92	10	73	31	28	47	44	49	43	65	3.58	+ 2.2	6	8,399	se.	37	se.	20	24	3	4	2.6	0.0	0.0
Wichita	1,358	139	158	28.58	30.01	− .02	62.8	+ 4.0	87	4	72	35	29	54	31	54	49	67	2.75	+ 0.4	7	10,939	s.	42	s.	11	15	7	9	3.8	0.0	0.0
Altus	1,410	5	......	......	......	......	65.0	......	91	5	77	39	29	53	38	......	......	......	3.04	......	5	......	se.	......	......	......		17	1	13	......	0.0	0.0
Broken Arrow	765	11	52	29.22	30.04	......	62.8	......	86	4	73	36	28	52	34	56	53	80	6.13	......	10	10,086	s.	39	se.	14	14	6	11	4.8	0.0	0.0
Muskogee	652	4	......	......	......	......	64.8	......	91	4	77	33	28	52	41	......	......	......	6.22	......	12	......	e.	......	......	......		18	4	9	......	0.0	0.0
Oklahoma	1,214	10	47	28.75	30.02	− .01	63.9	+ 2.6	89	4	74	38	28	54	31	56	52	74	7.38	+ 5.6	9	10,636	s.	39	s.	13	17	6	8	3.9	0.0	0.0
Southern Slope.							64.3	+ 1.8										62	2.00	+ 0.1										3.8		
Abilene	1,738	10	52	28.20	29.99	− .02	67.0	+ 2.8	88	11	78	41	28	56	35	57	52	69	2.77	+ 0.4	9	8,373	s.	37	s.	30	15	9	7	4.1	0.0	0.0
Amarillo	3,676	10	49	26.26	29.97	− .03	60.7	+ 4.6	91	9	74	35	28	48	39	49	42	64	1.87	+ 0.2	9	8,631	se.	36	sw.	14	19	7	5	3.9	0.0	0.0
Del Rio	944	64	71	29.00	29.98	.00	70.0	+ 0.1	88	6	80	42	26	60	34	......	......	......	2.47	+ 0.5	7	7,098	se.	30	n.	21	16	5	10	4.3	0.0	0.0
Roswell	3,566	75	85	26.35	29.93	− .03	59.4	− 0.1	89	3	75	29	28	44	44	47	37	52	0.89	− 0.6	3	5,925	s.	38	ne.	24	20	6	5	2.9	0.0	0.0
Southern Plateau.							57.3	+ 2.3										47	0.54	0.0										2.7		
El Paso	3,762	110	133	26.17	29.90	− .02	63.2	+ 0.8	88	3	76	35	24	51	35	48	34	42	0.57	− 0.4	4	8,098	e.	50	ne.	24	21	7	3	2.7	T.	0.0
Santa Fe	7,013	57	66	23.24	29.93	− .03	48.8	− 1.2	74	3	60	22	22	38	31	38	29	54	1.42	+ 0.4	7	5,656	sw.	38	s.	20	11	14	6	4.5	1.5	0.0
Flagstaff	6,908	8	57	23.30	29.87	− .05	42.8	− 1.9	75	3	57	10	21	29	48	34	......	......	3.08	......	8	......	sw.	35	n.	23	19	8	4	......	19.0	8.0
Phoenix	1,108	76	81	28.73	29.88	.00	67.0	− 3.2	98	5	82	39	22	52	41	53	44	52	0.46	+ 0.1	3	3,687	e.	26	s.	30	22	6	3	2.5	0.0	0.0
Yuma	141	9	54	29.75	29.89	+ .02	68.5	− 3.9	96	5	84	42	21	53	40	54	43	49	0.15	0.0	1	3,629	w.	29	n.	23	27	2	2	1.2	0.0	0.0
Independence	3,957	9	41	25.94	29.97	+ .02	54.0	− 4.3	85	1	68	28	19	40	39	40	25	37	0.11	− 0.2	1	4,590	nw.	30	w.	12	24	3	4	2.7	0.0	0.0
Middle Plateau.							47.4	−3.4										56	1.44	+0.6										4.6		
Reno	4,532	74	81	25.45	29.99	.00	46.6	−3.1	82	3	60	26	21	33	43	38	29	54	0.42	0.0	5	4,854	w.	44	w.	1	17	8	6	3.7	2.0	0.0
Tonopah	6,090	12	20	24.05	29.97	......	46.6	......	76	3	56	20	31	37	30	36	23	46	0.44	−0.4	4	7,303	se.	34	nw.	12	16	11	4	3.9	4.5	2.0
Winnemucca	4,344	18	56	25.60	30.02	−.03	44.6	−4.0	82	4	60	20	30	30	49	36	29	63	0.52	0.0	5	4,865	sw.	32	nw.	12	9	12	10	5.3	1.0	0.0
Modena	5,479	10	43	24.58	29.94	−.02	44.3	−5.9	81	3	60	15	21	29	47	34	23	51	2.40	+1.6	6	7,981	w.	46	s.	6	20	8	3	3.0	17.2	8.9
Salt Lake City	4,360	163	203	25.59	29.97	−.04	49.4	−2.8	84	4	58	29	24	41	31	41	35	64	3.57	+2.2	14	5,278	nw.	37	se.	5	8	10	13	6.4	5.4	0.0
Grand Junction	4,602	60	68	25.36	29.93	−.06	52.2	−1.1	81	4	64	29	26	40	36	42	33	56	1.29	+0.4	8	4,612	se.	40	sw.	10	12	7	12	5.0	3.0	0.0
Northern Plateau.							47.8	−1.6										66	1.62	+0.4										6.3		
Baker	3,471	48	53	26.43	30.05	− .03	44.0	−1.5	78	5	53	24	31	35	34	38	33	69	1.14	+0.2	9	4,761	se.	26	se.	6	8	8	15	6.2	T.	0.0
Boise	2,739	78	86	27.15	30.02	− .04	48.4	−1.9	83	5	58	26	30	38	34	42	36	65	2.34	+1.1	10	3,638	se.	24	nw.	1	11	6	14	6.0	T.	0.0
Lewiston	757	40	48	29.20	30.01	− .06	49.8	−2.0	79	5	60	26	31	40	33	......	......	......	1.60	+0.4	14	1,930	e.	24	nw.	6	7	8	16	6.5	0.0	0.0
Pocatello	4,477	60	68	25.45	30.00	− .04	44.8	−3.2	81	4	54	22	24	36	32	38	31	64	2.62	+1.6	14	6,209	se.	48	sw.	5	8	8	15	6.3	18.1	1.0
Spokane	1,929	101	110	27.95	30.01	− .05	48.0	+0.7	77	6	57	28	24	39	29	42	36	67	0.36	−1.2	8	4,854	sw.	32	sw.	1	6	11	14	6.6	T.	0.0
Walla Walla	991	57	65	28.93	30.01	− .06	52.0	−1.7	81	6	61	31	31	43	29	45	39	66	1.65	+0.2	13	3,376	s.	23	sw.	16	8	8	15	6.4	0.0	0.0
North Pacific Coast Region.							51.3	−0.5										84	5.73	+1.9										7.5		
North Head	211	11	56	29.76	29.98	− .07	51.6	−1.7	64	5	56	41	17	48	15	49	47	84	9.80	+5.9	22	12,107	se.	70	s.	13	5	10	16	6.5	0.0	0.0
Port Angeles	29	8	53	29.97	30.00	......	47.0	......	56	21	53	32	18	41	18	......	......	......	3.69	+1.1	18	3,443	s.	22	w.	21	5	3	23	7.9	0.0	0.0
Seattle	125	215	250	29.88	30.01	− .04	50.1	−0.7	64	5	55	34	31	45	19	47	45	84	4.19	+1.3	18	6,817	se.	39	s.	1	2	7	22	8.3	0.0	0.0
Tacoma	213	113	120	29.80	30.02	− .02	49.8	−0.8	63	5	55	29	31	44	25	48	46	87	5.14	+1.7	19	4,006	sw.	27	sw.	13	1	8	22	8.2	0.0	0.0
Tatoosh Island	86	7	57	29.85	29.95	− .06	51.0	+1.1	58	6	54	40	15	48	12	48	46	85	9.78	+1.8	22	12,282	e.	64	s.	3	6	4	21	7.2	0.0	0.0
Yakima	1,071	4	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Medford	1,425	4	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Portland, Oreg.	153	68	106	29.86	30.02	− .04	53.1	−0.2	73	4	59	38	31	47	19	49	46	80	3.71	0.0	21	4,477	s.	25	sw.	6	3	5	23	7.8	0.0	0.0
Roseburg	510	9	57	29.50	30.05	− .03	52.2	−0.6	77	4	60	30	31	44	27	49	46	82	3.78	+ 1.2	14	1,819	s.	18	w.	17	3	14	14	6.5	0.0	0.0
Middle Pacific Coast Region.							56.8	−2.0										69	2.12	+0.6										3.8		
Eureka	62	73	89	30.00	30.07	+ .01	54.6	+0.5	72	3	61	38	31	48	21	51	49	83	4.11	+1.5	16	5,019	se.	34	n.	29	12	5	14	5.5	0.0	0.0
Mount Tamalpais	2,375	11	18	27.55	30.03	+ .02	52.8	−5.9	73	3	58	38	19	48	19	46	40	69	2.09	+0.2	8	14,821	nw.	68	ne.	29	16	7	8	4.2	0.0	0.0
Point Reyes Light	490	7	18	29.47	29.99	......	55.1	+0.4	72	24	59	46	19	51	19	......	......	......	2.03	......	9	16,360	nw.	64	nw.	12	13	10	8	4.5	0.0	0.0
Red Bluff	332	50	56	29.64	30.00	− .03	58.8	−5.0	84	3	70	38	16	48	32	51	43	61	1.69	+0.1	7	4,743	n.	34	nw.	29	21	4	6	3.6	0.0	0.0
Sacramento	69	106	117	29.93	30.00	+ .01	58.6	−3.6	84	3	70	37	20	48	33	51	44	63	1.29	+0.2	6	5,181	nw.	35	nw.	30	19	9	3	2.8	0.0	0.0
San Francisco	155	208	243	29.85	30.02	+ .01	60.2	+1.8	78	23	67	49	26	53	25	53	48	71	1.83	+0.5	7	6,772	w.	38	n.	29	18	8	5	3.1	0.0	0.0
San Jose	141	12	110	29.88	30.03	......	57.8	−2.5	83	24	70	37	20	46	36	......	......	......	1.71	+0.8	9	4,611	nw.	30	w.	29	18	9	4	3.0	0.0	0.0
South Pacific Coast Region.							61.0	−1.9										66	0.75	−0.1										2.6		
Fresno	327	89	98	29.64	30.00	+ .04	60.0	−4.7	87	4	72	39	20	48	32	51	42	57	0.84	+0.1	6	3,940	nw.	25	nw.	12	24	5	2	1.9	0.0	0.0
Los Angeles	338	159	191	29.61	29.98	+ .03	63.2	−1.4	84	25	72	47	20	54	26	54	47	65	0.76	0.0	3	4,184	sw.	24	sw.	13	16	12	3	3.0	0.0	0.0
San Diego	87	62	70	29.87	29.96	+ .01	61.4	−1.6	77	25	68	45	21	55	24	55	51	73	0.18	−0.3	3	4,674	w.	24	se.	29	20	8	3	3.0	0.0	0.0
San Luis Obispo	201	32	40	29.79	30.01	+ .02	59.4	+0.2	86	3	72	35	31	47	41	50	45	68	1.23	−0.1	5	3,064	nw.	18	w.	12	20	9	2	2.5	0.0	0.0
West Indies.																																
San Juan, P. R	82	8	54	29.84	29.93	......	79.4	......	89	7	84	72	28	74	14	......	......	......	5.36	−0.7	17	5,789	ne.	34	e.	27	12	14	5	4.6	0.0	0.0
Panama Canal.																																
Balboa Heights	118	7	97	29.72	29.84	.00	79.7	+0.5	89	15	86	71	29	73	17	74	73	86	6.48	−3.7	22	4,452	nw.	30	s.	24	0	10	21	7.8	0.0	0.0
Colon	36	7	97	29.80	29.84	.00	80.9	+1.4	90	7	87	73	13	75	16	76	75	85	17.16	+2.1	26	4,745	w.	33	n.	1	0	6	25	8.4	0.0	0.0
Alaska.																																
Juneau	80	11	49	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during October, 1920, at all stations furnished with self-registering gages.*

Stations.	Date.	Total duration. From—	Total duration. To—	Total amount of precipitation.	Excessive rate. Began—	Excessive rate. Ended—	Amount before excessive rate began.	5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Abilene, Tex	19	1:20 p. m.	2:05 p. m.	0.53	1:32 p. m.	1:52 p. m.	0.01	0.07	0.17	0.38	0.52										
Albany, N. Y	27–28			0.54														0.27			
Alpena, Mich	26			0.53														0.13			
Amarillo, Tex	21			0.57														0.55			
Anniston, Ala	26			0.44														0.45			
Asheville, N. C	27			0.31														0.11			
Atlanta, Ga	27			0.31														0.27			
Atlantic City, N. J	28			0.58														0.20			
Augusta, Ga	27			0.91														0.63			
Baker, Oreg	11–12			0.26														(*)			
Baltimore, Md	28			0.17														0.05			
Bentonville, Ark	12	8:45 a. m.	10:20 a. m.	0.84	9:35 a. m.	10:05 a. m.	0.15	0.05	0.10	0.15	0.22	0.52	0.67								
Binghamton, N. Y	29			0.81														0.23			
Birmingham, Ala	26			0.23														0.20			
Bismarck, N. Dak	21			0.14														0.09			
Block Island, R. I	28			1.18														0.25			
Boise, Idaho	6			0.61														0.23			
Boston, Mass	28			0.89														0.21			
Buffalo, N. Y	11			0.51														0.27			
Burlington, Vt	1			1.04														0.44			
Cairo, Ill	26			1.09														0.38			
Canton, N. Y	26			0.43														0.13			
Charles City, Iowa	14–15	12:13 p. m.	12:40 a. m.	2.64	5:17 p. m.	5:27 p. m.	0.91	0.45	0.58												
Charleston, S. C	26			0.04														0.04			
Charlotte, N. C	27			0.10														0.03			
Chattanooga, Tenn	26			0.47														0.31			
Cheyenne, Wyo	31			0.54														(*)			
Chicago, Ill	15			0.19														0.11			
Cincinnati, Ohio	26			1.21														0.47			
Cleveland, Ohio	27			0.44														0.28			
Columbia, Mo	25			0.65														0.21			
Columbia, S. C	27			0.42														0.23			
Columbus, Ohio	19			0.36														0.36			
Concord, N. H	27–28			0.53														(*)			
Concordia, Kans	21			0.46														0.23			
Corpus Christi, Tex	24	D. N. a. m.	8:15 a. m.	1.07	3:10 a. m.	3:35 a. m.	0.08	0.11	0.30	0.48	0.60	0.70									
Dallas, Tex	18–19	9:45 p. m.	12:20 a. m.	0.98	11:28 p. m.	11:52 p. m.	0.34	0.12	0.32	0.40	0.57	0.62									
Davenport, Iowa	23			1.01														0.50			
Dayton, Ohio	26			0.76														0.24			
Del Rio, Tex	21			0.56														0.36			
Denver, Colo	30–31			0.34														(*)			
Des Moines, Iowa	14			0.81														0.27			
Detroit, Mich	26			1.29														0.32			
Devils Lake, N. Dak	23			0.09														0.08			
Dodge City, Kans	21			1.68														0.44			
Drexel, Nebr	14	10:20 a. m.	10:50 a. m.	0.53	10:31 a. m.	10:41 a. m.	0.02	0.26	0.50												
		1:50 p. m.	4:30 p. m.	1.32	1:57 p. m.	3:07 p. m.	0.04	0.15	0.39	0.48	0.55	0.58	0.60	0.64	0.75	0.82	0.85	0.96	1.14		
Dubuque, Iowa	15			0.96														0.37			
Duluth, Minn	13	2:26 p. m.	6:00 p. m.	1.36	2:56 p. m.	3:26 p. m.	0.02	0.06	0.12	0.21	0.33	0.44	0.50								
Eastport, Me	29			0.89														0.30			
Elkins, W. Va	27			0.75														0.37			
Ellendale, N. Dak	13			0.39														0.16			
El Paso, Tex	24			0.23														0.14			
Erie, Pa	26			0.53														0.34			
Escanaba, Mich	20			0.08														0.07			
Eureka, Calif	5			0.88														0.44			
Evansville, Ind	26			0.88														0.43			
*Flagstaff, Ariz																					
Fort Smith, Ark	17	4:28 a. m.	12:27 p. m.	1.75	5:25 a. m.	6:30 a. m.	0.03	0.07	0.18	0.25	0.39	0.42	0.47	0.51	0.60	0.66	0.78	1.13	1.37		
Fort Wayne, Ind	25			1.13														0.31			
Fort Worth, Tex	21	3:32 p. m.	5:41 p. m.	2.04	3:40 p. m.	3:59 p. m.	0.04	0.18	0.46	0.66	0.90										
					4:52 p. m.	5:11 p. m.	1.07	0.13	0.49	0.80	0.87										
Fresno, Calif	6			0.23														0.22			
Galveston, Tex	15	6:40 a. m.	6:54 p. m.	2.22	6:59 a. m.	7:14 a. m.	0.01	0.24	0.51	0.63											
	22	D. N. a. m.	8:05 a. m.	3.31	4:53 a. m.	6:23 a. m.	0.03	0.08	0.31	0.69	1.07	1.48	1.79	1.98	2.18	2.29	2.44	2.66	2.95	3.17	
Grand Haven, Mich	15			0.35														0.14			
Grand Junction, Colo.*	30			0.38														0.15			
Grand Rapids, Mich	15			0.40														0.27			
Green Bay, Wis	10			1.47														0.58			
Greenville, S. C	27			0.50														0.23			
Hannibal, Mo	15			0.22														0.14			
Harrisburg, Pa	27			0.47														0.29			
Hartford, Conn	12			0.13														0.13			
Hatteras, N. C	28			0.14														0.13			
Havre, Mont	7			0.54														0.26			
Helena, Mont	12			1.16														0.32			
Houghton, Mich	13			0.57														0.41			
Houston, Tex	15	3:15 a. m.	8:50 a. m.	1.83	4:12 a. m.	5:11 a. m.	0.03	0.18	0.29	0.40	0.58	0.80	0.97	1.15	1.26	1.36	1.40	1.52			
	21–22	4:25 p. m.	6:20 a. m.	2.61	1:46 a. m.	2:48 a. m.	0.28	0.16	0.32	0.50	0.78	1.10	1.31	1.35	1.36	1.48	1.64	1.76	1.80		
	23	1:48 p. m.	4:45 p. m.	2.73	1:50 p. m.	2:28 p. m.	0.01	0.24	0.78	1.26	1.75	2.10	2.30	2.47	2.57						
Huron, S. Dak	20–21			0.25														0.08			
Independence, Calif	18			0.11														0.07			
Indianapolis, Ind	18	3:27 p. m.	4:37 p. m.	0.55	3:29 p. m.	3:45 p. m.	0.01	0.18	0.39	0.48	0.51										
Iola, Kans	14	1:25 p. m.	4:50 p. m.	0.94	2:18 p. m.	2:33 p. m.	0.14	0.19	0.28	0.57											
Jacksonville, Fla	27			0.04														0.03			
Kalispell, Mont	29			0.09														0.08			
Kansas City, Mo	14			0.81														0.54			
Keokuk, Iowa	31			0.15														0.13			
Key West, Fla	14	12:40 p. m.	2:20 p. m.	0.99	1:05 p. m.	1:21 p. m.	0.03	0.40	0.77	0.92	0.95										
Knoxville, Tenn	27			0.65														0.30			
La Crosse, Wis	14–15			1.38														0.25			
Lander, Wyo	29–30			4.45														(*)			
Lansing, Mich	26			0.59														0.18			
Lewiston, Idaho	6			0.22														0.13			
Lexington, Ky	26–27	9:30 p. m.	7:30 a. m.	1.00	10:04 p. m.	10:26 p. m.	0.06	0.07	0.24	0.38	0.48	0.51									
Lincoln, Nebr	14	1:20 p. m.	2:45 p. m.	0.67	1:36 p. m.	2:10 p. m.	0.03	0.10	0.17	0.28	0.37	0.42	0.51	0.58							

* Self-register not in use.

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during October, 1920, at all stations furnished with self-registering gages*—Continued.

Stations.	Date.	Total duration. From—	Total duration. To—	Total amount of precipitation.	Excessive rate. Began—	Excessive rate. Ended—	Amount before excessive rate began.	5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Little Rock, Ark	24			1.80														0.60			
Los Angeles, Calif	30			0.29														0.26			
Louisville, Ky	26			1.08														0.71			
Ludington, Mich	10			0.60														0.24			
Lynchburg, Va	27			0.10														0.09			
Macon, Ga	27			0.41														0.13			
Madison, Wis	14			0.74														0.67			
Marquette, Mich	31			0.76														0.30			
Memphis, Tenn	24	10:45 a. m.	8:50 p. m.	1.19	3:03 p. m.	3:26 p. m.	0.45	0.07	0.23	0.40	0.48	0.54									
Meridian, Miss	24			0.75														0.45			
Miami, Fla	20			1.01														0.54			
Milwaukee, Wis	15			0.35														0.16			
Minneapolis, Minn	20	1:30 p. m.	3:00 p. m.	1.05	1:36 p. m.	2:46 p. m.	0.01	0.11	0.15	0.22	0.30	0.35	0.44	0.52	0.60	0.65	0.67	0.83	1.03		
Mobile, Ala	24	8:10 a. m.	9:25 p. m.	4.20	2:06 p. m.	3:05 p. m.	1.27	0.10	0.18	0.23	0.27	0.28	0.35	0.54	0.61	0.67	0.94	1.19			
Modena, Utah	29-30			2.02														(*)			
Montgomery, Ala	26			0.97														0.70			
Moorhead, Minn	21			0.23														0.22			
Mount Tamalpais, Calif	6			0.64														0.24			
Nantucket, Mass	1			1.42														0.71			
Nashville, Tenn	26-27			2.50														0.66			
New Haven, Conn	28			0.55														0.19			
New Orleans, La	23	12:50 p. m.	1:25 p. m.	0.62	1:01 p. m.	1:11 p. m.	0.02	0.29	0.60												
New York, N. Y	28			0.44														0.15			
Norfolk, Va	28			0.86														0.59			
Northfield, Vt	1			1.03														0.55			
North Head, Wash	17			1.62														0.39			
North Platte, Nebr	14			0.35														0.21			
Oklahoma, Okla	18	6:25 a. m.	10:45 a. m.	0.88	6:50 a. m.	7:28 a. m.	0.01	0.09	0.19	0.35	0.40	0.45	0.48	0.53	0.64						
Omaha, Nebr	14			0.76														0.47			
Oswego, N. Y	16			0.27														0.22			
Palestine, Tex	14-15	9:30 p. m.	D. N. a. m.	0.73	11:57 p. m.	12:15 a. m.	0.10	0.11	0.22	0.43	0.50										
Parkersburg, W. Va	27			0.82														0.29			
Pensacola, Fla	27			0.54														0.54			
Peoria, Ill	23			1.18														0.23			
Philadelphia, Pa	27-28			0.50														0.13			
Phoenix, Ariz	19-20			0.28														0.11			
Pierre, S. Dak	21			0.80														0.17			
Pittsburgh, Pa	27			0.67														0.20			
Pocatello, Idaho	19			0.89														(*)			
Point Reyes Light, Calif	6			0.73														0.33			
Port Angeles, Wash	11			0.29														0.20			
Port Huron, Mich	26			0.74														0.26			
Portland, Me	28			0.46														0.19			
Portland, Oreg	12			0.42														0.20			
Providence, R. I	28			1.19														0.27			
Pueblo, Colo	14			0.35														0.14			
Raleigh, N. C	27	3:40 p. m.	8:20 p. m.	1.59	5:02 p. m.	5:27 p. m.	0.12	0.25	0.37	0.41	0.46	0.61									
Rapid City, S. Dak	31			0.81														(*)			
Reading, Pa	27			0.80														0.40			
Red Bluff, Calif	11			0.76														0.54			
Reno, Nev	18			0.29														(*)			
Richmond, Va	27			0.43														0.22			
Rochester, N. Y	16			0.21														0.19			
Roseburg, Oreg	18			1.12														0.34			
Roswell, N. Mex	24			0.58														0.11			
Sacramento, Calif	6			0.37														0.28			
Saginaw, Mich	11			0.54														0.50			
St. Joseph, Mo	14			1.12														0.54			
St. Louis, Mo	23			1.21														0.54			
St. Paul, Minn	19			0.37														0.27			
Salt Lake City, Utah	12			0.34														0.21			
San Antonio, Tex	14	7:27 p. m.	8:50 p. m.	1.16	7:46 p. m.	8:27 p. m.	0.01	0.05	0.13	0.36	0.73	0.78	0.83	0.96	1.05	1.11					
San Diego, Calif	19			0.14														0.06			
Sand Key, Fla	21			0.17														0.17			
Sandusky, Ohio	26-27	7:55 p. m.	D N a. m.	1.46	11:58 p. m.	12:49 a. m.	0.29	0.07	0.14	0.20	0.31	0.42	0.62	0.73	0.85	0.93	0.99	1.05			
Sandy Hook, N. J	28			0.66														(*)			
San Francisco, Calif	6			0.85														0.42			
San Jose, Calif	6			0.66														(*)			
San Luis Obispo, Calif	19			0.25														0.22			
Santa Fe, N. Mex	30-31			1.01														(*)			
Sault Ste. Marie, Mich	15			0.05														0.03			
Savannah, Ga	27			0.36														0.35			
Scranton, Pa	27			1.12														0.57			
Seattle, Wash	6			0.61														0.15			
Sheridan, Wyo	11			0.72														0.14			
Shreveport, La	15			0.75														0.55			
Sioux City, Iowa	14			1.16														0.31			
Spokane, Wash	3			0.10														0.07			
Springfield, Ill	23-24			0.55														0.30			
Springfield, Mo	14			2.22														0.73			
Syracuse, N. Y	16			0.17														0.09			
Tacoma, Wash	5			0.46														0.28			
Tampa, Fla	27			0.07														0.05			
Tatoosh Island, Wash	20			0.87														0.20			
Taylor, Tex	14-15	7:05 p. m.	12:15 a. m.	7.52	7:26 p. m.	8:16 p. m.	0.07	0.46	0.77	0.98	1.01	1.04	1.24	1.47	1.77	2.06	2.41				
					8:16 p. m.	9:06 p. m.	0.07	2.49	2.73	3.14	3.56	3.80	4.03	4.24	4.56	4.75	5.11				
					9:06 p. m.	9:45 p. m.	0.07	5.44	5.67	6.07	6.59	6.89	7.08	7.12	7.41						
Terre Haute, Ind	25			0.77														0.15			
Thomasville, Ga	27			1.07														0.69			
Toledo, Ohio	27			0.65														0.35			
Tonopah, Nev	30			0.28														(*)			
Topeka, Kans	14	10:55 a. m.	4:00 p. m.	1.09	1:13 p. m.	1:45 p. m.	0.27	0.14	0.22	0.30	0.34	0.41	0.50	0.57							
Trenton, N. J	28			0.66														0.27			
Valentine, Nebr	20			0.23														0.23			
Vicksburg, Miss	23			0.21														0.18			
Walla Walla, Wash	18			0.55														0.14			

* Self-register not in use.

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during October, 1920, at all stations furnished with self-registering gages*—Continued.

Stations.	Date.	Total duration. From—	Total duration. To—	Total amount of precipitation.	Excessive rate. Began—	Excessive rate. Ended—	Amount before excessive rate began.	5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min
Washington, D. C.	28			0.31														0.23			
Wausau, Wis.	20			0.84														0.45			
Wichita, Kans.	20			1.61														0.60			
Williston, N. Dak.	22			0.41														0.18			
Wilmington, N. C.	27–28			0.48														(*)			
Winnemucca, Nev.	18			0.22														0.08			
Wytheville, Va.	27			0.08														0.03			
Yankton, S. Dak.	15			0.66														0.36			
Yellowstone Park, Wyo.	15			0.55														(*)			

* Self-register not in use.

TABLE III.—*Data furnished by the Canadian Meteorological Service, October, 1920.*

Stations.	Altitude above mean sea level Jan. 1, 1919.	Pressure. Station reduced to mean of 24 hours.	Pressure. Sea level reduced to mean of 24 hours.	Pressure. Departure from normal.	Temperature of the air. Mean max. + mean min. ÷ 2.	Temperature of the air. Departure from normal.	Temperature of the air. Mean maximum.	Temperature of the air. Mean minimum.	Temperature of the air. Highest.	Temperature of the air. Lowest.	Precipitation. Total.	Precipitation. Departure from normal.	Precipitation. Total snowfall.
	Feet.	*Inches.*	*Inches.*	*Inches.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	*Inches.*	*Inches.*	*Inches.*
St. Johns, N. F.	125	29.62	29.76	−.15	45.1	−0.3	50.9	39.4	72	28	6.49	+1.14	0.0
Sydney, C. B. I.	48	29.91	29.96	.00	51.0	+4.5	59.1	42.9	74	31	0.52	−4.17	0.0
Halifax, N. S.	88	29.88	29.99	−.01	51.6	+4.4	60.4	42.8	74	32	1.52	−4.03	0.0
Yarmouth, N. S.	65	29.93	30.00	−.02	51.4	+3.8	59.3	43.5	70	31	1.09	−3.61	0.0
Charlottetown, P. E. I.	38	29.91	29.95	−.01	50.4	+3.9	57.1	43.8	69	32	0.76	−4.14	0.0
Chatham, N. B.	28	29.94	29.97	+.01	51.0	+8.0	60.5	41.4	72	33	5.24	+1.38	0.0
Father Point, Que.	20	29.92	29.94	−.01	44.2	+4.4	55.0	38.5	64	27	2.26	−0.64	0.0
Quebec, Que.	296	29.68	30.00	.00	49.4	+7.0	56.7	42.2	67	30	5.26	+2.11	T.
Montreal, Que.	187	29.80	30.01	.00	52.1	+7.3	57.2	45.0	71	31	3.07	−0.06	0.2
Stonecliffe, Ont.	489	29.40	29.96	−.04	42.6	−0.2	61.8	23.5	82	16	1.75	−0.68	0.3
Ottawa, Ont.	236	29.77	30.02	+.01	52.2	+8.4	63.0	41.4	75	30	2.81	+0.26	0.0
Kingston, Ont.	285	29.75	30.06	+.03	54.1	+7.1	61.2	47.0	70	32	1.99	−0.74	0.0
Toronto, Ont.	379	29.66	30.07	+.03	54.9	+8.3	64.3	45.5	81	33	3.83	+1.47	0.3
Cochrane, Ont.	930												
White River, Ont.	1,244	28.67	29.99	+.01	45.8	+8.7	58.8	32.8	74	1	1.48	−0.87	0.5
Port Stanley, Ont.	592												
Southampton, Ont.	656	29.34			54.2	+8.1	61.3	47.2	79	34	2.97	−0.20	T.
Parry Sound, Ont.	688	29.39	30.09	+.08	52.1	+8.2	61.1	43.1	76	29	3.36	−0.56	4.7
Port Arthur, Ont.	644	29.28	29.99	+.01	49.7	+9.8	57.7	41.8	75	23	1.41	−1.15	0.0
Winnipeg, Man.	760	29.07	29.90	−.08	49.0	+9.9	60.2	37.8	83	16	0.21	−1.49	0.0
Minnedosa, Man.	1,690	28.07	29.90	−.07	45.6	+7.8	56.9	34.4	84	18	1.76	+0.56	0.0
Le Pas, Man.	860												
Qu'Appelle, Sask.	2,115	27.60	29.84	−.13	45.5	+6.1	56.3	34.8	85	19	1.67	+0.57	T.
Medicine Hat, Alb.	2,144	27.55	29.82	−.15	47.3	+2.5	59.2	35.5	85	25	1.28	−0.70	T.
Moose Jaw, Sask.	1,759												
Swift Current, Sask.	2,392	27.28	29.90	−.07	45.2	+3.1	57.0	33.4	88	20	1.08	+0.20	0.6
Calgary, Alb.	3,428	26.31	29.89	−.06	42.0	+1.9	56.0	28.0	84	15	1.49	+1.01	5.2
Banff, Alb.	4,521	29.29	29.87	−.08	38.4	−0.8	47.0	29.9	68	18	0.90	−0.12	4.7
Edmonton, Alb.	2,150	27.52	29.91	−.02	40.0	−1.1	51.8	28.3	72	15	0.78	+0.08	1.6
Prince Albert, Sask.	1,450	28	29.86	−.11	44.0	+6.9	56.1	32.0	80	18	1.06	+0.23	0.4
Battleford, Sask.	1 592	28.09	29.83	−.14	43.1	+3.5	55.4	30.9	79	22	1.83	+1.38	0.0
Kamloops, B. C.	1,262	28.71	30.02	+.06	45.0	−2.0	52.7	37.3	62	21	1.07	+0.46	0.0
Victoria B. C.	230	29.72	29.97	−.04	48.5	−0.7	52.7	44.2	59	37	4.03	+1.66	0.0
Barkerville, B. C.	4,180	25.55	29.91	−.03	32.7	−7.0	39.7	25.7	61	13	6.11	+3.41	26.7
Triangle Island, B. C.	680												
Prince Rupert, B. C.	170												
Hamilton, Ber.	151	29.90	30.06	−.04	74.7	+1.7	81.2	68.2	87	63	3.11	−3.60	0.0

SEISMOLOGY.

W. J. HUMPHREYS, Professor in Charge.

[Dated: Weather Bureau, Washington, D. C., Dec. 3, 1920.]

TABLE 1.—*Noninstrumental earthquake reports, October, 1920.*

Day.	Approximate time, Greenwich civil.	Station.	Approximate latitude.	Approximate longitude.	Intensity Rossi-Forel.	Number of shocks.	Duration.	Sounds.	Remarks.	Observer.
		CALIFORNIA.								
1919.	H. m.		° ′	° ′			Sec.			
Oct. 4	13 21	Eureka	40 48	124 10	2	1	3	None	Felt by several	L. B. Cooper.
5	4 46	do	40 48	124 10	4	1	4	do	Some alarm	J. M. Jones.
5	19 04½	Salinas	36 36	121 40	5	1	20	do	No damage	E. D. Eddy.
		Spreckles	36 35	121 38	5	4	2,1,3,4	Faint	Felt by many	S. I. Gleason.
	19 05	Los Gatos	37 12	121 58	3	1		None	Felt by several	F. H. McCullagh.
		San Jose	37 15	121 53	3	1	4		do	Maurice Connell.
	19 07	San Francisco	37 48	122 26	4?	1	1	None	Doors and dishes rattled	Mrs. R. N. Allen.
		do	37 48	122 26	3	1	2	do	Felt by several	M. W. Davis.
7	5 33	do	37 48	122 26	3?	1	4	do	Felt by two	M. W. Allen.
12	17 45	Warner Springs	33 15	116 45	6-7	1	2	Rumbling	Felt by many	J. A. Ream.
	17 48	Aguanga	33 30	117 00	5	1	2	do	do	A. J. Berg.
	17 48½	San Diego	32 43	117 10	3	1	30	None	Felt inland also	H. F. Alciatore.
	17 51	Hemet	33 45	116 45	3	1	1-2	do	Felt by many	C. E McManigal.
	17 58	Calexico	32 41	115 30	2-3	1	30	do	Felt by several	W. S. Pratt.
31	6 32	El Centro	32 50	115 35	2	2	1	Faint	do	J. M. Bartley.
		MISSOURI.								
3	14 15	Harrisonville	38 45	94 15	2	2		None	Felt all over town	J. H. Patterson.

TABLE 2.—*Instrumental seismological reports, October, 1920.*

Time used: Mean Greenwich, midnight to midnight. Nomenclature: International.

[For significance of symbols see REVIEW for January, 1920, pp. 62-63.]

ALABAMA. *Spring Hill College, Mobile.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920.			H. m. s.	Sec.	μ	μ	Km.	
Oct. 8		O	16 50 23				1,550	N undamped; no trace on E.
		P_N	16 53 43					
		S_N	16 56 25					
		L_N	16 57 13					
		M_N	16 57 25	6		*4,000		
		F_N	17 18 00					

CALIFORNIA. *Theosophical University, Point Loma.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920.			H. m. s.	Sec.	μ	μ	Km.	
Oct. 5					150	150		Tremors.
6					100	100		
7					200	200		
10					100	100		
12			17 51 00		300	400		Light shock.
13					300	300		Tremors.
14					100	200		
16					100	100		
17					100	150		
21					100	100		
24					100	100		
25					100	150		
29					100	100		

COLORADO. *Sacred Heart College, Denver.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920.			H. m. s.	Sec.	μ	μ	Km.	
Oct. 1		L_E	19 02 ..					P not discernible.
		L_N	19 02 ..					
		M_E	19 04 ..	10-12	*3,000			
		M_N	19 05 ..	4- 6		*1,000		
		C_E	19 09 ..					
		C_N	19 09 ..					
		F	19 19 ..					
22		L	21 15 ..					P not discernible; record weak and disturbed
		M	21 21 ..	10-12	*500	*500		
		F	22 44 ..					

* Trace amplitude.

DISTRICT OF COLUMBIA. *Georgetown University, Washington.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920.			H. m. s.	Sec.	μ	μ	Km.	
Oct. 1		e_E	19 01 09					Heavy micros.
		e_N	19 01 09					
		eL?	19 16 42					
		F	19 58 ..					
5		e_E	19 19 19					
		e_N	19 19 17					
		F	19 40 ..					
7		eP_E	21 03 21					N-S component out of order.
		iS_E	21 11 13					
		eL_E	21 19 30	22				
8		eP_E	16 56 47					Do.
		S_E	17 01 41					
		eL_E	17 05 18					
		L_E	17 11 20					
		F	17 48 ..					
18		iP_E	8 23 14					Do.
		iS_E	8 33 30					
		eL_E	8 48 30					
		L_E	8 59 ..	22				
		F	9 50 ..					
22		iP_Z	12 19 46					Heavy micros.
		eS_Z	12 28 55					
		eL_Z	12 41 54					
		F	13					
28		L_Z	8 08 30	24				Do.
		F	8 12 ..					
28		eP_E	13 00 00					Sheets off at 13h. 51m., quake still on.
		iP_N	12 59 55					
		iS_E	13 10 20					
		eS_N	13 10 11					
		eL	13 22 06	23				

DISTRICT OF COLUMBIA. *U. S. Weather Bureau, Washington.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920.			H. m. s.	Sec.	μ	μ	Km.	
Oct. 1		P?	18 56 06					
		S	19 01 06					
		eL	19 08 45					
		F	19 30 ca					

TABLE 2.—*Instrumental seismological reports, October, 1920*—Continued.

DISTRICT OF COLUMBIA. *U. S. Weather Bureau, Washington*—Con.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Oct. 3								Clock stopped; record lost.
7		P	21 03 06				5,700	
		S	21 10 26					
		L	21 18 20					
		F	21 40 ..					
8		P	16 56 24				3,400	
		S	17 01 32					
		M	17 07 25		*2,000	*2,000		
		F	17 30 *ca*					
18		P	8 24 09				9,100	
		S	8 34 24					
		L	8 52 14					
		F	8 40 *ca*					
18		e	12 33 20					
		F	12 40 50					
18		e	13 57 ..					
		S?	14 14 ..					
		F	14 40 ..					
20		eL	12 09 ..					
		F	12 25 ..					
22		P	12 20 05				6,700	
		S	12 28 20					
		L	12 39 20					
		F	13 00 00					
27		P	11 48 44				2,400	
		S	11 52 44					
		F	11 56 44					
27		P	11 57 24					
		S	11 01 12					
		F	12 15 ..					
28		P	7 31 47					
		S?	7 40 45					
		e	8 00 00					
		F	8 20 ..					
28		iP	12 59 59					
		S	13 08 48					
		eL	13 23 ..					
		F	13 40 ..					

ILLINOIS. *U. S. Weather Bureau, Chicago.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920.			*H. m. s.*	*Sec.*	μ.	μ.	*Km.*	
Oct. 1		P	18 55 34				3,000	
		S	19 00 19					
		eL	19 06 06	15				
		F	20 20 *ca*					
3		e_E	5 42 30					
		eL	5 46 ..	16				
		F	6 30 *ca*					
5		e	19 17 25					
		eL	19 20 ..					
		F	19 40 *ca*					
7		P	21 03 54				5,700	
		S	21 11 12					
		L	21 17 49	25				
		M	21 21 25		*4,000	*4,000		
		F	22 20 *ca*					
8		P	16 56 18					
		S?	17 01 18					
		L?	17 04 20					
		L?	17 06 00					
		F	18 *ca*					
12		eL	7 46 ..					
		L	7 50 ..	22				
		L	8 00 ..	16				
		F	8 20 *ca*					
18		P	8 23 38				8,600	
		PR1	8 26 39					
		S	8 33 29					
		L	8 49 45	20				
		L	9 02 ..	18				
		F	11 *ca* ..					
18		e	12 16 06					
		S?	12 24 22					
		F	12 50 ..					
18		e	13 03 10					
		F	14 20 *ca*					

* Trace amplitude.

ILLINOIS. *U. S. Weather Bureau, Chicago*—Continued.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Oct. 20		L	10 54 21					
		L	11 06 30	16				
		F	11 40 *ca*					
22		P	12 20 26				7,300	
		S	12 29 10					
		L	12 42 ..	30				
		L	12 52 ..	16				
		F	14 30 *ca*					
24		eL	2 36 15					
		L	2 38 30	18				
		F	3 10 ..					
27		S?	11 55 25					
		L?	11 58 25					
		F	13 00 00					
28		P	7 33 50				6,500	
		S	7 41 55					
		L	7 52 16	25				
		L	7 58 ..	22				
		L	8 03 ..	16				
		F	11 *ca* ..					
28		P	13 01 18				8,100	
		S	13 10 45					
		L	13 25 38	30				
		L	14 00 00	18				
		L	14 09 ..	14				
		F	15 20 *ca*					

NEW YORK. *Cornell University, Ithaca.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Oct. 7		eP_N	21 04 01	3				
		eS	21 11 18	4				
		L_E	21 18 10	27				
		F	21 33 ..					
8		e	16 57 30	4				Irregular, short period waves.
		e	17 01 22	5				
		F	17 18 ..					
18		P	8 24 05	4				
		PR_1	8 27 19	4				
		S	8 34 15	5				
		eL	8 51 56	30				
		F	9 21 ..					
18		e	12 33 36	9				
		F	12 41 ..					
18		e	13 07 30	4				
		e	13 12 35	10				
		e	13 21 04	11				
		F	13 37 ..					
22		P	12 20 33	4				
		S	12 29 05	6				
		eL	12 41 15	14				
		F	13 14 ..					
28		eL	8 00 30	18				
		F	8 13 ..					
28		P	13 01 22	5				
		PR_1	13 03 50	4				
		eS	13 26 30	18				
		F	13 45 ..					

VERMONT. *U. S. Weather Bureau, Northfield.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Oct. 8		e	17 06 ..					
		F	17 15 ..					
18		P	8 24 ..				9,000	
		S	8 34 10					
		L?	8 50 ..					
		F	9 15 *ca*					
18		e	13 14 ..					
		F	13 30 ..					
22								Clock stopped; record lost.
28		e	13 01 50					
		F	13 15 ..					

* Trace amplitude.

TABLE 2.—*Instrumental seismological reports, October, 1920*—Continued.

CANAL ZONE. *Panama Canal, Balboa Heights.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920.			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Oct. 7		P	20 59 06				2,494	Epicenter probably in Mexico.
		S_E	21 03 04					
		S_N	21 03 10					
		M_E	21 03 42		*1,500			
		M_N	21 04 12			*900		
		F_E	21 17 00					
		F_N	21 16 15					
22		P_E	12 16 26				3,460	Distance from Washington, 6,920 km. Direction unknown.
		P_N	12 16 25					
		S_E	12 21 35					
		S_N	12 21 48					
		M_E	12 22 20		*500			
		M_N	12 21 53			*1,500		
		F_E	12 35 00					
		F_N	12 47 00					
28		P_N	12 57 20					Very slight on EW; dist. 4,311 km. ca., dir. S.; timer not rec. on EW.
		S_N	13 03 25					
		M_N	12 59 20			*500		

CANADA. *Dominion Observatory, Ottawa.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920.			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Oct. 1		e	19 02 25					Micros interfere with registration of preliminary phases.
		e	19 11 54					
		F	20 00 ..					
5		e	19 22 30					
		eL?	19 23 ..					
		L	19 24 18					
			to 30 ..	10				
		F	19 50 ..					
7		O	20 55 18				5,700	
		P	21 04 31					
		S	21 11 51					
		i_E	21 12 33					
		i_E	21 14 11					
		eL_E	21 19 16					
		L_E	21 22 ..	28				
		L	21 30 ..	22				
		L	21 40 ..	16				
		F	22 *ca* ..					
8		O?	16 50 28				(3,600)	
		P	16 57 16					
		S_N	17 02 40					
		eL	17 06 25					Irregular waves in L phase.
		F	17 50 *ca*					
18		O	8 11 49				8,780	LR1 recorded sharply on deformation instrument, 10:30.
		iP_V	8 23 50					
		iS_V	8 33 49					
		eL_V	8 52 24					
		L_V	8 55 ..	28				
		F_V	9 *ca* ..					
			HALIFAX.					
		O	8 11 52				9,100	Halifax and Ottawa together indicated epicenter in Kurile Ids.
		eP_N	8 24 10					
		iS_N	8 34 26					
		eL	8 52 56					
20		e_E	10 54 30					
		eL_E	11 03 30	24				
		F	11 20 ..					
22		O	12 09 51				7,390	
		iP_{NV}	12 20 46					
		i_N	12 25 30					
		iS_{NV}	12 29 35					
		i_E	12 30 20					
		i_{EN}	12 31 22					
		eL	12 37 30					Irregular.
		L	13 00 ..	18				
		F	13 18 ..					
24		eL_E	2 42 40					
		F	2 50 *ca*					
28		e_E	(7 43 00)					
		eL_E	7 53 08					
		L	7 56 48	20				
		L	8 02 45	16				
		L	8 19 00	12				
		F	8 50 ..					

* Trace amplitude.

CANADA. *Dominion Observatory, Ottawa*—Continued.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920.			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Oct. 28		O	12 50 11				8,080	
		P_N	13 01 36					
		$PR1_N$	13 04 45					
		$PR2_N$	13 06 21					
		S_N	13 11 00					Press reports quake 900 miles from La Plata.
		i_N	13 11 24					
		i_N	13 12 12					
		$SR1_N$	(13 16 14)					
		$SR2_N$	(13 19 10)					
		eL_{NE}?	13 25 08					
		L	13 26 45	24				
		L	13 28 ..	28				
		F	14 30 ..					

CANADA. *Dominion Meteorological Service, Toronto.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920.			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Oct. 1								Light off 19:06 to 19:10 attending instrument; quake lost.
7		i	21 00 54					Micros render readings doubtful.
		S	21 09 00					
		i	21 13 42					
		L	21 17 24					
		M?	21 18 48		*600			
		eL	21 40 54					
		F						Micros.
8		e:	17 01 06					Small micros going on.
		S?	17 04 30					
		eL	17 08 48					
		M	17 09 54		*400			
		F						Micros.
12		eL	7 53 54					
		F	7 56 54		*100			
15		eL	14 54 30					
		F	14 57 30		*200			
18		i	8 17 36					Faint record.
		P	?8 26 24					
		i	8 27 24					
		S	8 34 42					
		L	8 42 48					
		eL	8 58 24					
		M?	9 05 54		*1000			
		L	9 43 30					
		F	9 56 42					
18		L	13 12 54					Faint trace.
		eL	13 20 06					
		M	13 22 06		*400			
		F						
20		eL	11 07 36					
		M	11 10 30		*300			
		eL	11 19 18					
		eL	11 25 24					
		F	11 28 24					
22		L	12 05 42					May not be seismic.
		F	12 08 48		*100			
22		iS	12 29 30					P indistinct.
		i	12 30 06					
		M	12 31 42		*1,200			
		eL	12 41 42					
		eL	12 55 24					
		M2	12 59 42		*300			
		F	13?30 06					
24		L	2 34 06					
		eL	2 42 12					
		M	2 43 00		*200			
		eL	2 58 24					
26		L	19 25 48					
		F	19 28 48		*200			
28		e	7 43 48					
		eL	7 59 12					
		M	8 01 06					
		eL	8 17 36		*300			
		F	8 25 30					
28		e	13 00 36					P very minute; S well defined; Chili.
		P	13 01 12					
		iS	13 11 00					
		M	13 12 06		*800		8,560	
		i	13 13 54					
		iS	13 15 54					
		iSR2	13 19 42					
		eL	13 25 30					
		F	14 08 06					

*Trace amplitude.

TABLE 2.—*Instrumental seismological reports, October, 1920*—Contd.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
CANADA. *Dominion Meteorological Service, Victoria.*								
1920.			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Oct. 1		P?	19 10 10				1,400	Probably Alaska.
		M	19 12 37		*1,000			
		F	19 21 28					
5		L	19 10 51					Pender Island reported quake a 12:35 p. m. Pacif. Stand. Time.
		M	19 12 49		*400			
		F	19 17 15					
7		P?	21 06 18				8,300?	
		S	21 15 53					
		L	21 29 10					
		M	21 34 05		*500			
		F	22 35 27					
8		S?	17 07 47					
		L?	17 12 17					
		L	17 14 29					
		M	17 17 05		*300			
		F	17 37 23					
12		P	7 43 56					
		L	7 47 23					
		M	7 53 46		*200			
		F	7 58 41					
15		L	14?56 12					
		M	14 58 40		*500			
		F	15 07 02					
18		P	8 15 58					
		S	8 21 02					
		L	8 28 25					
		M	8 36 46		*1,000		3,170	
		F	10 03 20					
18		P	12 14 00					
		M	12 15 14		*200			
		F	12 17 27					
18		P	12 52 20				450	Merged into next quake.
		M	12 53 19		*500			
				VERTICAL.				
		P	*12 53 10*	*2*			520	
		L	*12 54 25*	*7*				
		M	*12 54 25*	*10*		3		
		F	*13?02 00*					
18		P	13 01 12				660	
		M	13 02 41		*1,000			
		F	13 12 01					
				VERTICAL.				
		P	*13 02 00*	*2.5*			840	
		L	*13 04 00*	*5*				
		M	*13 04 15*	*7*	7			
		F	*13 14 00*					
20		P	10 43 12					
		M	11 00 25		*200			
		F	11 33 22					
22		S or L	12 33 00					
		eL	12 48 10					
		M	12 57 35		*500			
		F	13 43 20					
23								Clock stopped.
26		P	19 30 29					
		L	19 31 58					
		M	19 33 26		*200			
		F	19 34 25					
28		L	7 36 31					
		M	7 44 23		*400			
		F	8 29 38					
28		P?	13 05 06? or 08 03					Press dispatches say 900 miles from La Plata.
		S or L	13 12 58					
		eL	13 13 08					
		M	13 13 57		*500			
		eL	13 20 40					
28		P	13 31 39					
		L	13 35 35					
		M	13 40 01		*1,100			
		F	15 20 50					

*Trace amplitude.

Reports for October, 1920, have not been received from the following stations:

ALASKA. *U. S. C. & G. S. Magnetic Observatory*, Sitka.
ARIZONA. *U. S. C. & G. S. Magnetic Observatory*, Tucson.
HAWAII. *U. S. C. & G. S. Magnetic Observatory*, Honolulu.
KANSAS. *University of Kansas*, Lawrence.
MARYLAND. *U. S. C. & G. S. Magnetic Observatory*, Cheltenham.
MASSACHUSETTS. *Harvard University*, Cambridge.
MISSOURI. *St. Louis University*, St. Louis.
NEW YORK. *Canisius College*, Buffalo; *Fordham University*, New York.
PORTO RICO. *U. S. C. & G. S. Magnetic Observatory*, Vieques.

SEISMOLOGICAL DISPATCHES.

[Collected by Earthquake Station, Georgetown University, Washington, D. C.]

Clarmont-Ferrant, France, October 4.—An earth shock was felt this morning in the vicinity of Issoire, Department of Puy-de-Dome. The tremors lasted only a few seconds and no damage was reported.—*Associated Press.*

London, October 8.—Two violent earth tremors were felt in Mantua, Northern Italy, at midnight Wednesday, according to a telegram to the Rome Epoca, says a Central News dispatch from Rome, dated Thursday. The inhabitants fled into the streets in alarm. The message reported some property damage had been caused.—*Associated Press.*

Mexico City, October 9.—Reports received here of an earthquake yesterday in Northwestern Vera Cruz say there were no casualties.—*Associated Press.*

Vera Cruz, October 9.—Northwestern sections of the State of Vera Cruz were severely shaken by an earthquake at 10:30 o'clock yesterday morning. The regions of Cordoba, Jalapa, Teccele, Cosautlan and the entire district which was visited by the earthquake disaster of last January felt the full strength of the shock. No casualties had been reported, but property damage was said to be heavy.—*Associated Press.*

Manila, P. I. October 10.—A severe earthquake to-day at Baguis, capital of Bengust, Province of Yuzon, about 150 miles north of here, damaged the observatory there, broke water mains on the military reservation and cracked a number of concrete walls. A landslide occurred as a result of high water in the river at Baguio. No loss of life was reported. The shock was felt slightly in Manila.—*Associated Press.*

Toulouse, France, October 20.—Earthquake shocks were felt yesterday in several places in the Hautes Pyrennese Department.—*Associated Press.*

Granada, Spain, October 23.—An earthquake shock lasting 10 minutes was felt at 6 o'clock Friday evening throughout the Province. Damage was done in some villages, but it has not been ascertained as yet whether there were any casualties.—*Associated Press.*

Redding, Calif., October 27.—Lassen Peak was in pronounced eruption to-day. For more than half an hour, beginning at 2:40 p. m., black smoke rolled out of the northern part of the crater. To-day's eruption was the second outpouring in less than a week. A substantial outbreak occurred Saturday.—*Associated Press.*

Valparaiso, October 28.—Violent earthquake shocks with a vertical movement shook the Provinces of Atacama and Coquimbo, north of this city, at 8:05 o'clock this morning, the tremors lasting 2½ minutes. The cities of Copiape and Valanar, in the Province of Atacama, were most seriously shaken, old structures in both towns being damaged. Reports received here state no one was injured during the earthquake.—*Associated Press.*

NEWSPAPER CLIPPINGS.

[By the Associated Press.]

Washington, October 22.—An earthquake shock of considerable intensity was recorded by the seismograph of the Georgetown University at 7:19 o'clock this morning, continuing for nearly an hour. It is estimated that the center of the disturbance was 4,300 miles from Washington.

Buenos Aires, October 28.—El seismografo de la Universidad de la Plata ha registrado un fuerte terremoto a las 8.52 minutos. Se estima que el centro del disturbio esta situadoa a 1,400 kilometros de distancia.

LATE REPORTS.

TABLE 2.—*Instrumental reports.*

ALABAMA. *Spring Hill College, Mobile.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920.			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
July 7		P_N	18 06 48					N component undamped; no trace on EW.; time uncertain.
		M_N	18 11 30					
		F_N	18 20 00					

DISTRICT OF COLUMBIA. *Georgetown University, Washington.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920.			H. *m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Sept. 7		eL	6 26 ..					
8		e_E	2 06 33					
		e_N?	2 06 16					
		i_E	2 10 42					
		S_E?	2 11 45					
		S_N?	2 11 54					
		i_N	2 20 44					
		eL_E	2 21 30	22				
		L_E	2 45 16	22				
		F	3 30 ..					
9		eL_E	19 58 ..					
		L_E	20 01 24	24				
		F	20 45 ..					
20		eP_E	14 57 55					No distinct M on MS.
		eP_N	14 57 55					
		i_E	15 06 22					
		eS_E	15 09 17					
		eS_N	15 09 17					
		eL_E	15 28 24					
		eL_N	15 29 18					
		L_E	15 38 ..	27				
		L_N	15 38 14	22				
		M_E1	15 41 00	24	*2,000			
		M_E2	15 48 00	20	*2,200			
		F	17 45 ..					
				VERTICAL.				
		e_Z	*14 58 ..*					
		S_Z	*15 09 30*					
		eL_Z	*15 28 24*	*22*				
		L_N	*15 37 35*	*24*				
		M_Z	*15 44 26*			*900		
		F	*17 20 ..*					
21		e_E	18 05 ..					
		e_N	18 05 14					
24		eP_E	22 01 43					Heavy micros.
		eP_N	22 01 43					
		S_E	22 07 04					
		S_N	22 07 07					
		eL	22 10 06					
		L_E	22 13 28	19				
		F	22 33 ..					
27		e_E	5 42 ..					Do.
		e_N	5 42 ..					
		S_E?	5 45 17					
		F	6 00 ..					

ARIZONA. *U. S. C. & G. S. Magnetic Observatory, Tucson.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920.			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Sept. 8		eP_E	1 58 20					L waves not distinguishable.
		P_N	1 58 22					
		eS_E	2 08 37		30			
		iS_N	2 08 38			40		
		F_N	2 17 ..					
		F_E	3 09 ..					
20		P	14 52 22	4				Phases well marked.
		S_N	15 02 50	5				
		S_E	15 02 54					
		L_E	15 21 05	34				
		L_N	15 22 35	23				
		M_N	15 28 30	18		10		
		M_E	15 32 15	18	80			
		C_N	15 33 ..	17				
		C_E	15 41 ..	16				
		F_N	15 45 ..	17				
		$L_{RE\,PIE}$	16 58 ..	20				
		F_E	17 17 ..					

*Trace amplitude.

ARIZONA. *U. S. C. & G. S. Magnetic Observatory, Tucson*—Con.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920.			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Sept. 24		P_E	22 02 15	4				
		P_N	22 02 18	4				
		PR_E	22 03 42					
		PR_N	22 03 50					
		eS_N	22 08 11					
		S_E	22 08 14					
		eL_N	22 13 45					
		L_E	22 14 45					
		M_E	22 15 27	9	20			
		M_N	22 17 27	8		20		
		C_N	22 18 ..					
		C_E	22 19 ..					
		F_N	22 27 ..					
		F_E	22 28 ..					
27		e_N	5 27 10					
		e_E	5 27 38					
		L_N	5 28 27					
		L_E	5 28 23					
		M_E	5 28 58		250			
		M_N	5 29 34			160		
		C_E	5 30 38					
		C_N	5 32 30					
		F_N	5 45 ..	7				
		F_E	5 52 ..	6				
29		e_E	12 00 57					
		e_N	12 01 04					
		eL_E	12 01 30					
		M_E	12 02 29	6	20			
		M_N	12 02 50	6		10		
		C_E	12 03 ..					
		C_N	12 04 ..					
		F_E	12 05 ..					
		F_N	12 06 ..					

HAWAII. *U. S. C. & G. S. Magnetic Observatory, Honolulu.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920.			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Sept. 1		L	3 08 00					Tremor.
		M	3 13 00	17	*100			
		C	3 17 ..					
		F	3 22 ..					
	3	L	3 42 54					Tremor.
		M	3 45 00	17	*100			
		C	3 53 ..					
		F	3 56 ..					
	8	P	1 54 24	17				Clock stopped 2.22, and remainder of record lost; L difficult to place.
		iS	2 00 36	17				
		eL	2 07 ..					
		M	2 17 00	17	*1,100			
	9	eP	19 04 48	20				L difficult to place.
		eS	19 12 18	17				
		eL	19 21 00	18				
		M	19 26 48	16	*1,700			
		C	19 58 ..	17				
		F	22 04 ..	20				
	10	e	22 21 36					Slight record.
		eL	22 26 00					
		M	22 32 00	17	*100			
		C	22 37 ..					
		F	23 12 ..					
	20	iP	14 48 36	16				L indistinguishable from the S waves.
		PR	14 51 24	16				
		iS	14 56 18	16				
		SR	15 00 48					
		M	15 10 06	17	*35,000			
		C	16 26 ..	17				
		F	21 56 ..	17				
21		eP	2 51 24					
		L	2 58 36					
		M	3 09 12	18	*1,100			
		C	3 12 30					
		F	3 47 12					
21		e	5 21 00					
		L	5 31 30					
		M	5 36 00	17	*200			
		C	5 41 ..					
		F	6 06 ..					

*Trace amplitude.

Table 2.—*Instrumental reports*—Continued.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
Hawaii. *U. S. C. & G. S. Magnetic Observatory, Honolulu*—Con.								
1920.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Sept. 21		P	17 56 54	17				
		eS	18 01 00	17				
		eL	18 04 00	19				
		M	18 13 18	19	*400			
		C	18 17 ..	19				
		F	19 11 ..	17				
23		P	5 48 18	17				L difficult to place.
		S	5 52 48	17				
		eL	5 55 48	17				
		M	6 11 42	17	*200			
		C	6 13 54	17				
		F	6 57 ..					
24		eS	22 16 30	17				This interpretation adopted after comparison with Tucson and Vieques.
		L	22 29 06	17				
		M	22 36 48	17	*900			
		C	22 39 ..					
		F	23 30 ..					
Maryland. *U. S. C. & G. S. Magnetic Observatory, Cheltenham.*								
1920.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Sept. 8		e_N	2 10 44					L waves not clearly present. Nothing on E-W.
		i_N	2 20 45			50		
		F_N	2 42 ..					
20		i_E	14 58 05					P tremors faint in both components.
		e_N	15 04 55					
		eS_N	15 16 09					
		L_E	15 38 11	28				
		L_N	15 39 49					
		M_E	15 46 36	18	90			
		M_N	15 51 27	17		290		
		C_E	15 50 ..	18				
		C_N	16 00 ..	17				
		F_E	16 24 ..	17				
		F_N	17 21 ..	17				
27		e_N	5 42 28					L waves not clearly present on E-W.
		e_E	5 42 35					
		eL_N	5 42 43					
		M_N	5 43 46	12		40		
		C_N	5 46 ..	9				
		F_E	5 48 ..					
		F_N	5 58 ..					
Porto Rico. *U. S. C. & G. S. Magnetic Observatory, Vieques.*								
1920.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Sept. 8		ePR_N	2 06 34					L waves not present; interpretation adopted after comparison with Tuscon and Honolulu.
		ePR_E	2 06 52					
		S_E	2 15 06					
		F_N	2 20 ..					
		F_E	2 29 ..					
20		$ePR1_N$	15 01 36					This interpretation adopted after comparison with Tucson and Honolulu.
		$ePR1_E$	15 01 35					
		$ePR2_E$	15 05 20					
		$iSR1_E$	15 18 09	16				
		L_E	15 40 06	38				
Porto Rico. *U. S. C. & G. S. Magnetic Observatory, Vieques*—Con.								
1920.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Sept. 20		L_N	15 41 13	23				
		M_E	15 42 01	26	70			
		M_N	15 42 50	24		60		
		C_N	15 49 ..	18				
		C_E	15 58 ..	18				
		$L_{EE\,FIE}$	16 44 ..					
		F_N	16 59 ..	18				
		F_E	17 17 ..	16				
24		iP	21 59 46	6				Long waves not present on NS; P and S both well marked.
		iS	22 03 45	13				
		L_E	22 05 13					
		M_E	22 05 24	10	30			
		C_E	22 06 ..					
		F_N	22 11 ..					
		F_E	22 28 ..					
Massachusetts. *Harvard University, Cambridge.*								
1920.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Aug. 3		O	19 57 15	3			7,770	69° .93 arc; E gives P and S less distinct; M phases distorted by winding drums.
		P_N	20 08 24.5	3				
		S_N	20 17 32.5					
		eL_N	20 31 32.5	58				
		M_E	20 36 ..	20				
		C	20 40 *ca.*					
		F_E	21 44 *ca.*					
13		e_N	2 13 04	3				Possibly only a group of micros; not recognizable as possibly seismic on E record; weak micros were running before and after these phases.
		F	2 14 37					
		e_N	2 21 24	3				
		F	2 23 56					
20		O?	16 14 59				9,315?	Distance from L–S; L difficult to fix. Record indistinct on NS.
		e_E	16 27 07					
		S_E	16 37 53					
		L??	16 51 47	20				
		L_E	16 55 49	25				
		L	17 05 23	18				
		L	17 17 00	16				
		L	18 04 31	16				
		F	18 41 *ca.*					
21		L_E?	21 32 20	15				Not legible on N. Periods decrease rapidly to 8 secs.
		L	21 34 36	15				
		F	21 38 37					
26		O?	22 58 55				8,050?	Deduced terms from E.; L-0/8050 kms. gives VL 231.6 kms. per sec. S_N doubtfully fixed. iPS 23-10-18. Great irregularity in period after initial L.
		iP_E?	23 10 19	2				
		S_N	23 18 59	6				
		S_E	23 19 41	6				
		e_N	23 30 54	7				
		eL_N	23 33 10	26				
		eL_E	23 33 17	25				
		L_E	23 36 30	20				
		L_N	23 39 00	20				
		L_N	23 43 00	15				
27		F_E	0 36 *ca.*					

*Trace amplitude.

Chart I. Hydrographs of Several Principal Rivers, October, 1920.

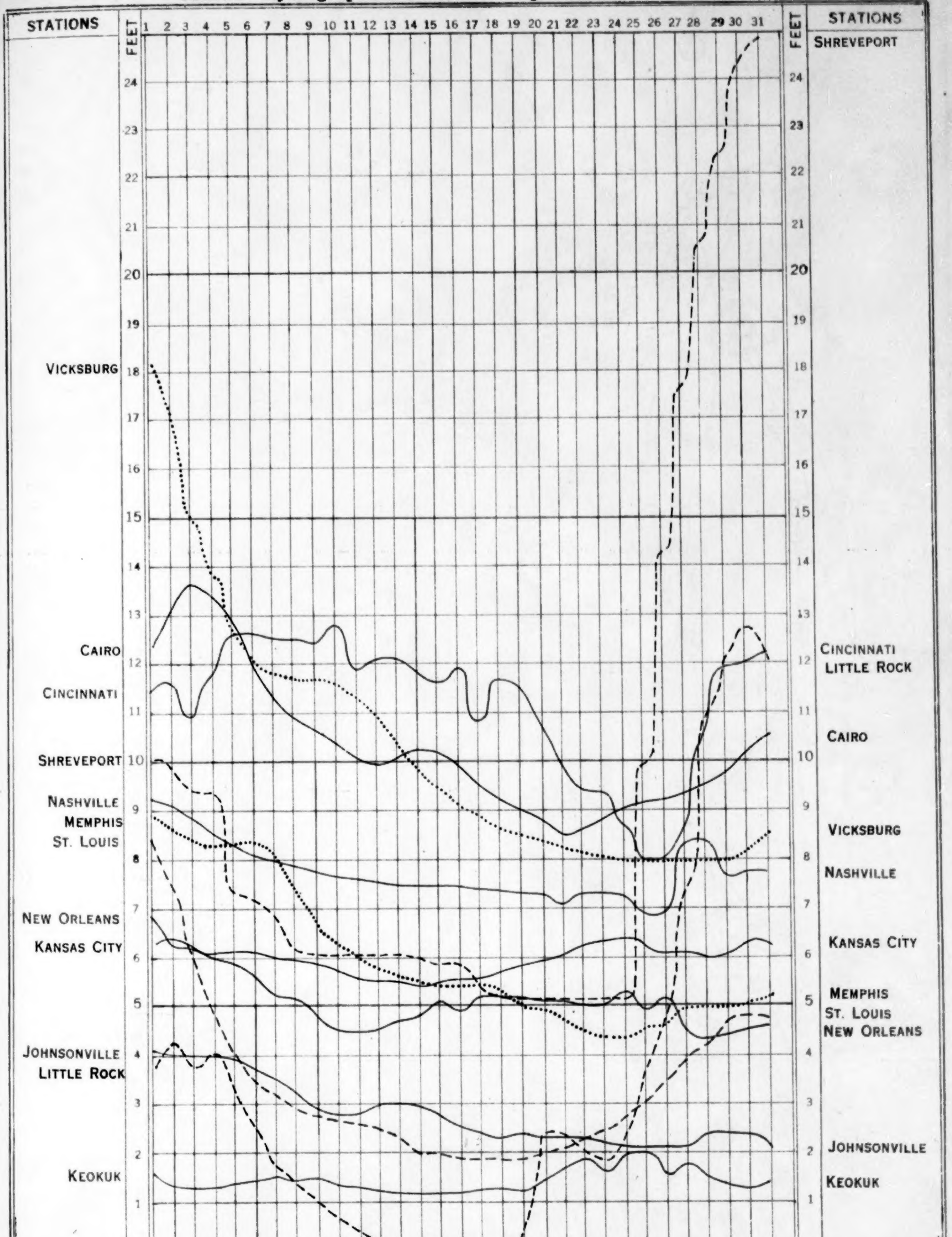


Chart II. Tracks of Centers of High Areas, October, 1920.

(Plotted by Wilfred P. Day.)

Chart III. Tracks of Centers of Low Areas, October, 1920.
(Plotted by Herbert Lyman.)

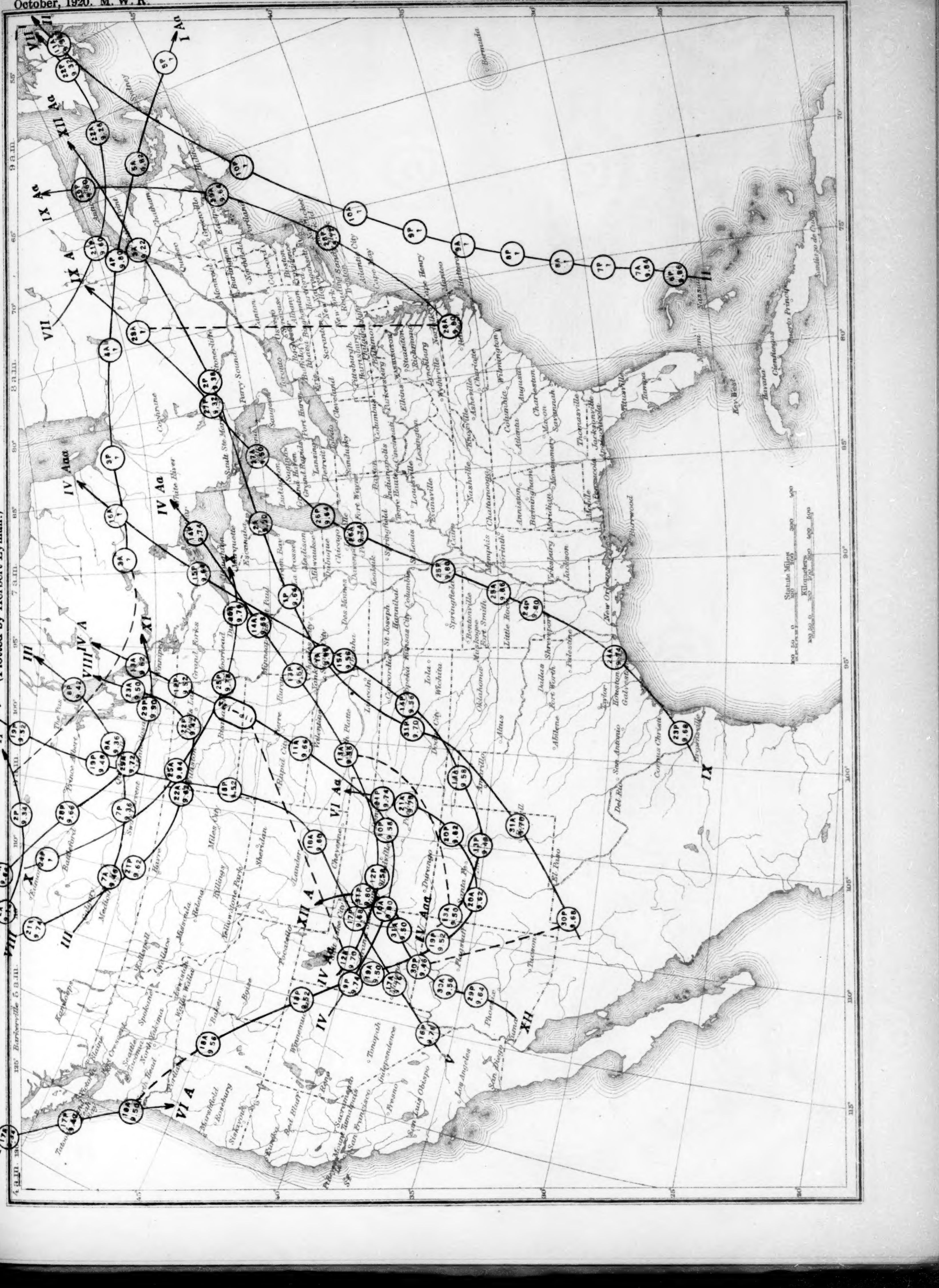
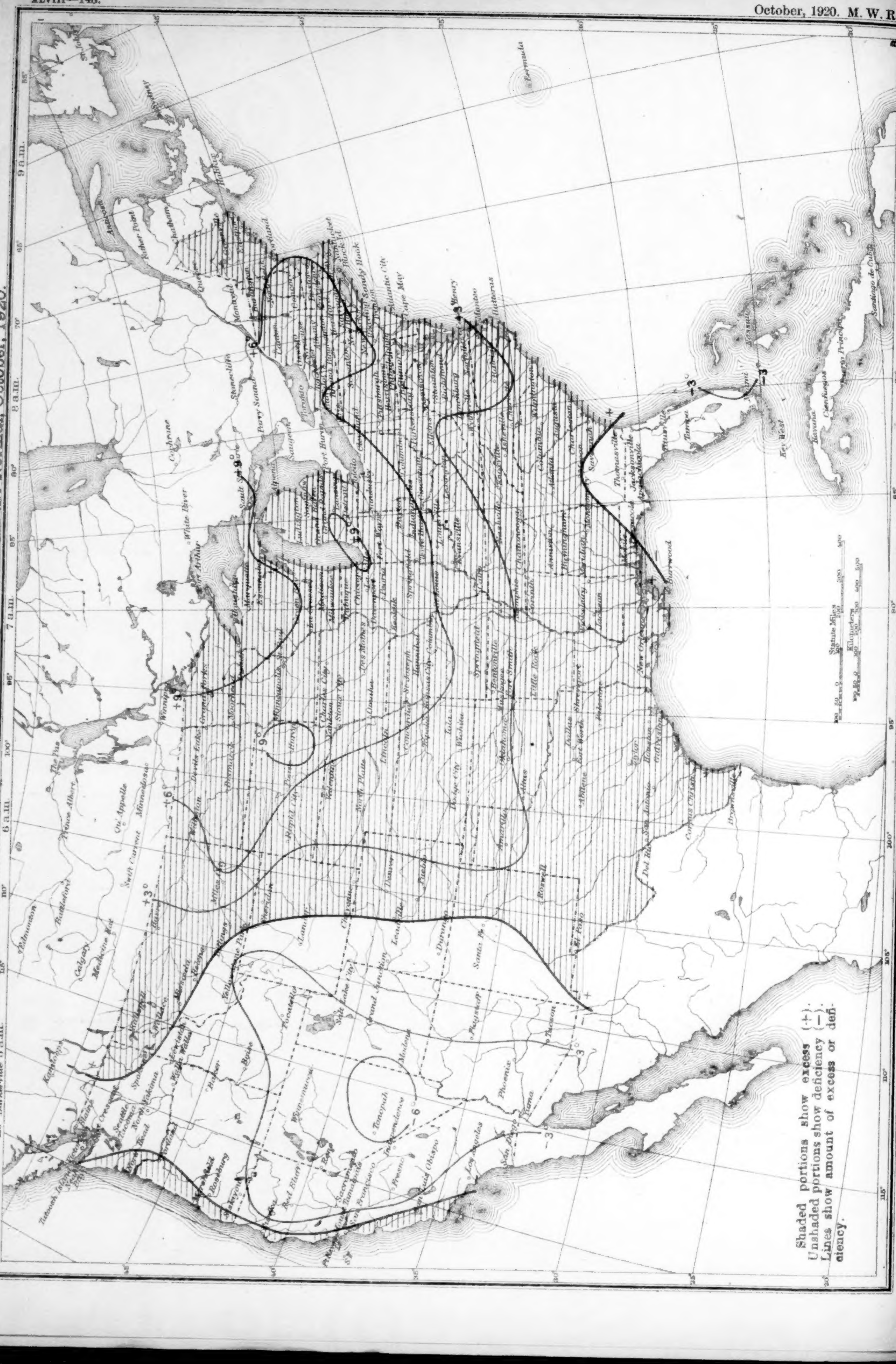


Chart IV. Departure (°F.) of the Mean Temperature from the Normal, October, 1920.



Shaded portions show excess (+).
Unshaded portions show deficiency (−).
Lines show amount of excess or deficiency.

Chart V. Total Precipitation, Inches, October, 1920.

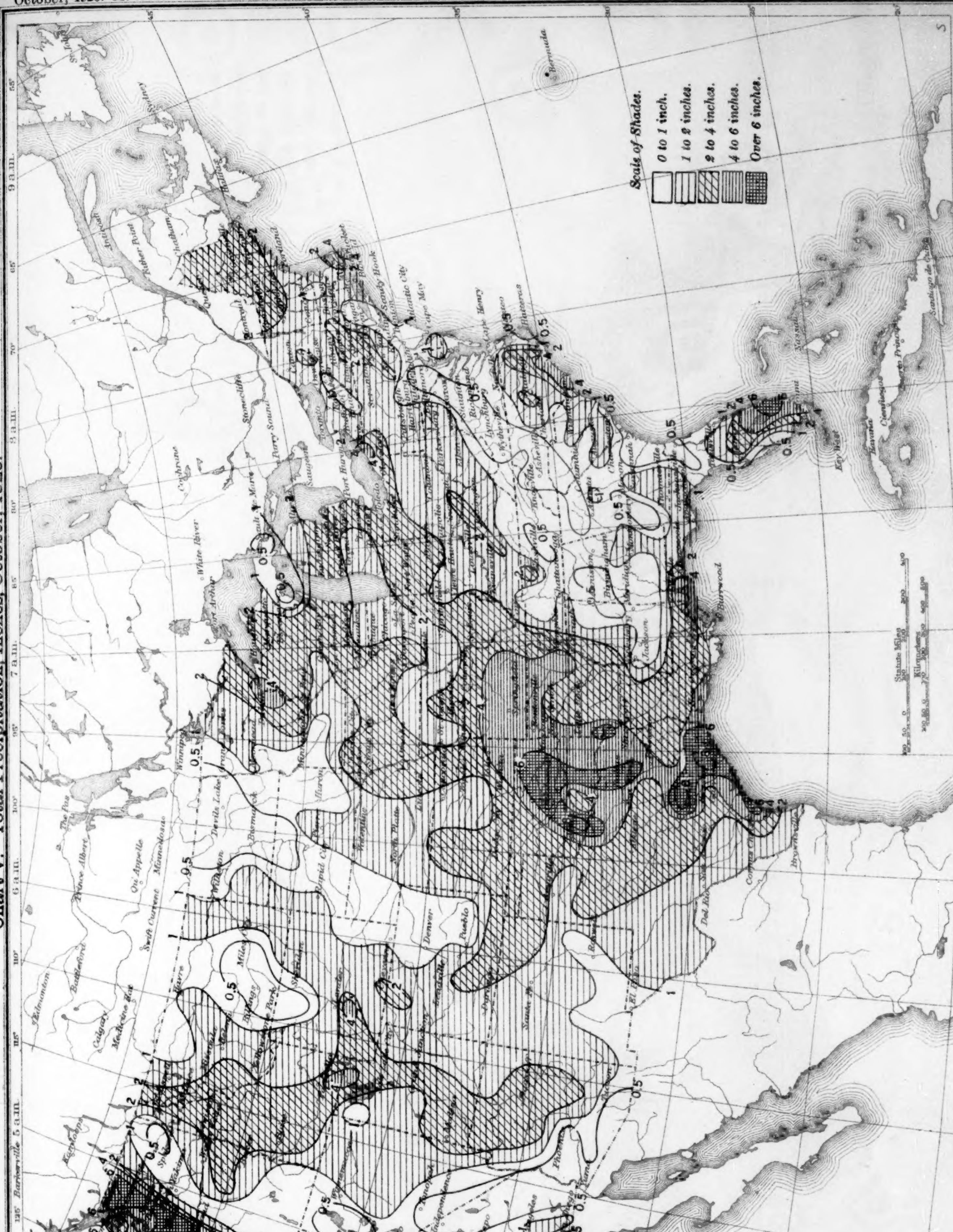


Chart VI. Percentage of Clear Sky between Sunrise and Sunset, October, 1920.

Chart VII. Isobars and Isotherms at Sea-level; Prevailing Winds, October, 1920.

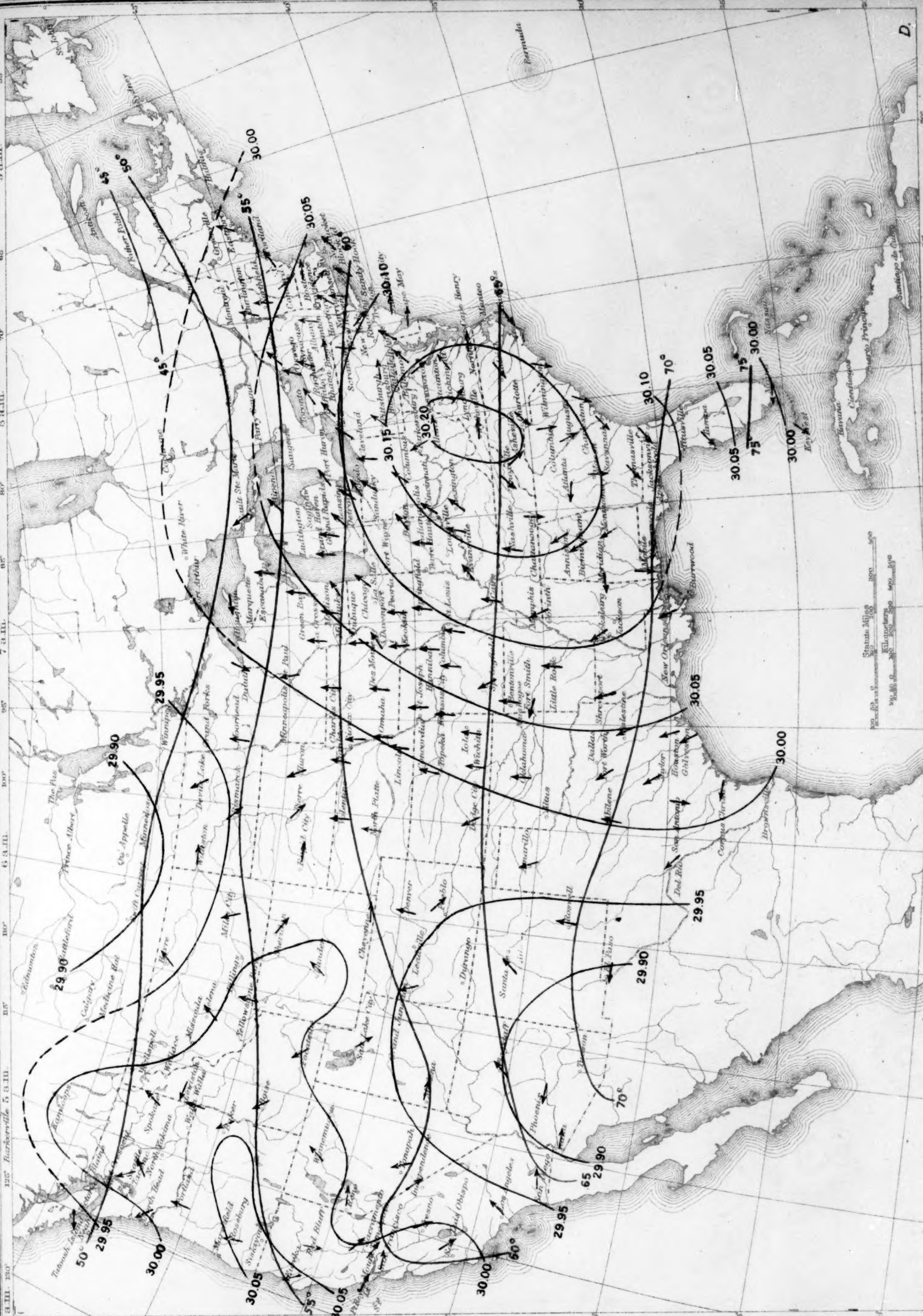


Chart IX. Weather Map of North Atlantic Ocean, October 3, 1920.

Chart IX. Weather Map of North Atlantic Ocean, October 3, 1920.
(Plotted by F. A. Young.)

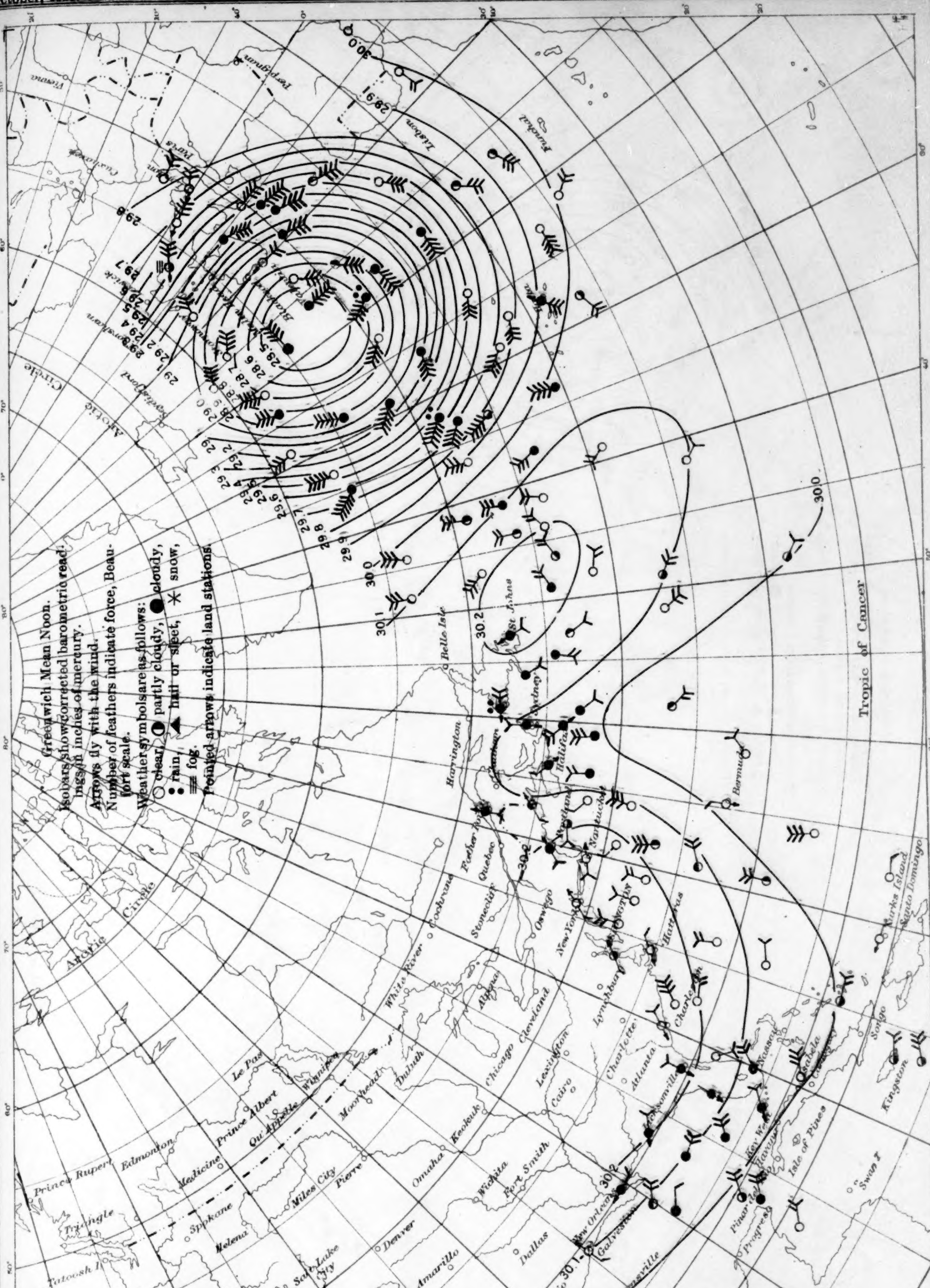


Chart X. Weather Map of North Atlantic Ocean, October 4, 1920.

(Plotted by F. A. Young.)

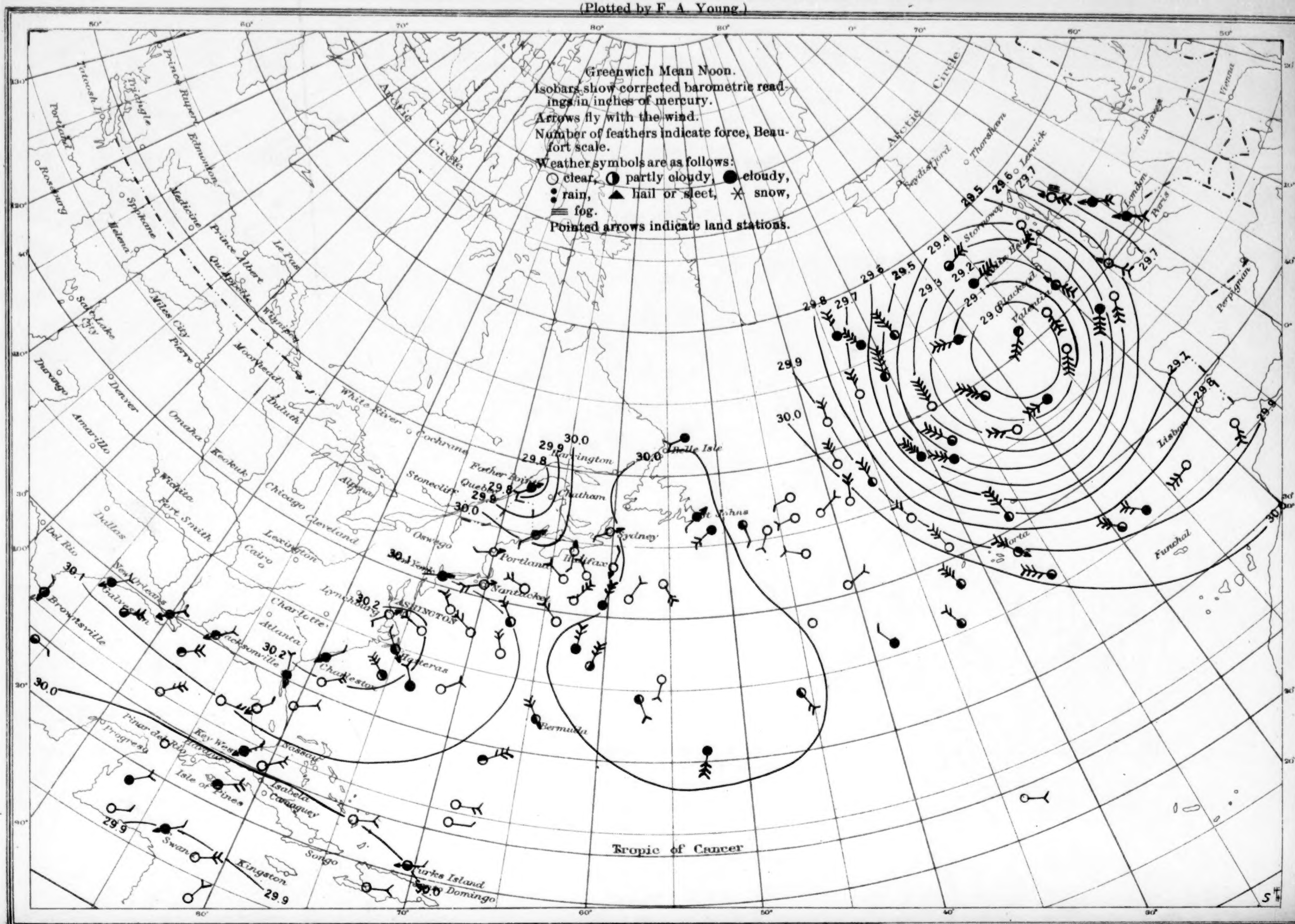


Chart XI. Weather Map of North Atlantic Ocean, October 17, 1920.
(Plotted by F. A. Young.)

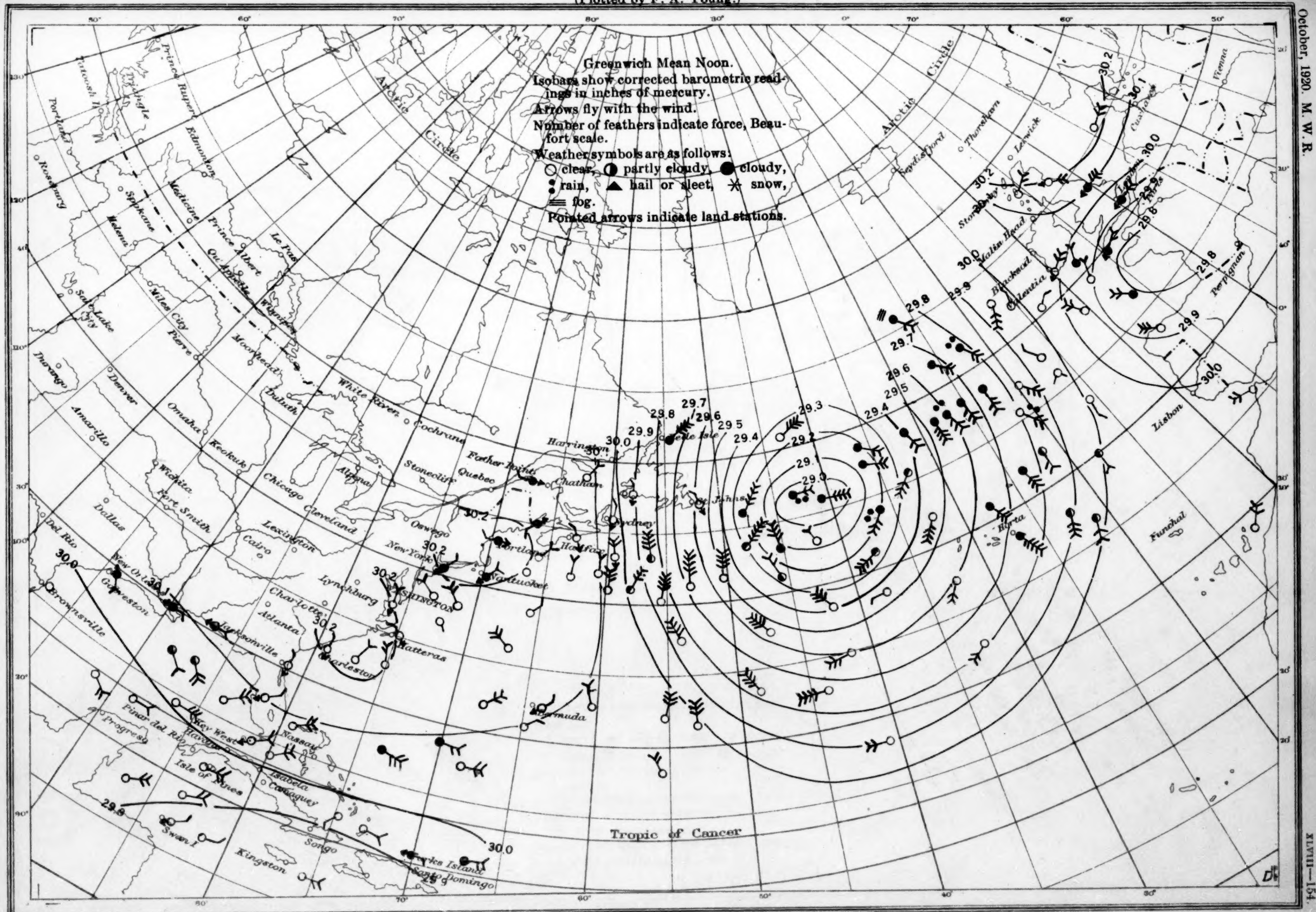


Chart XII. Weather Map of North Atlantic Ocean, October 18, 1920.

(Plotted by F. A. Young.)

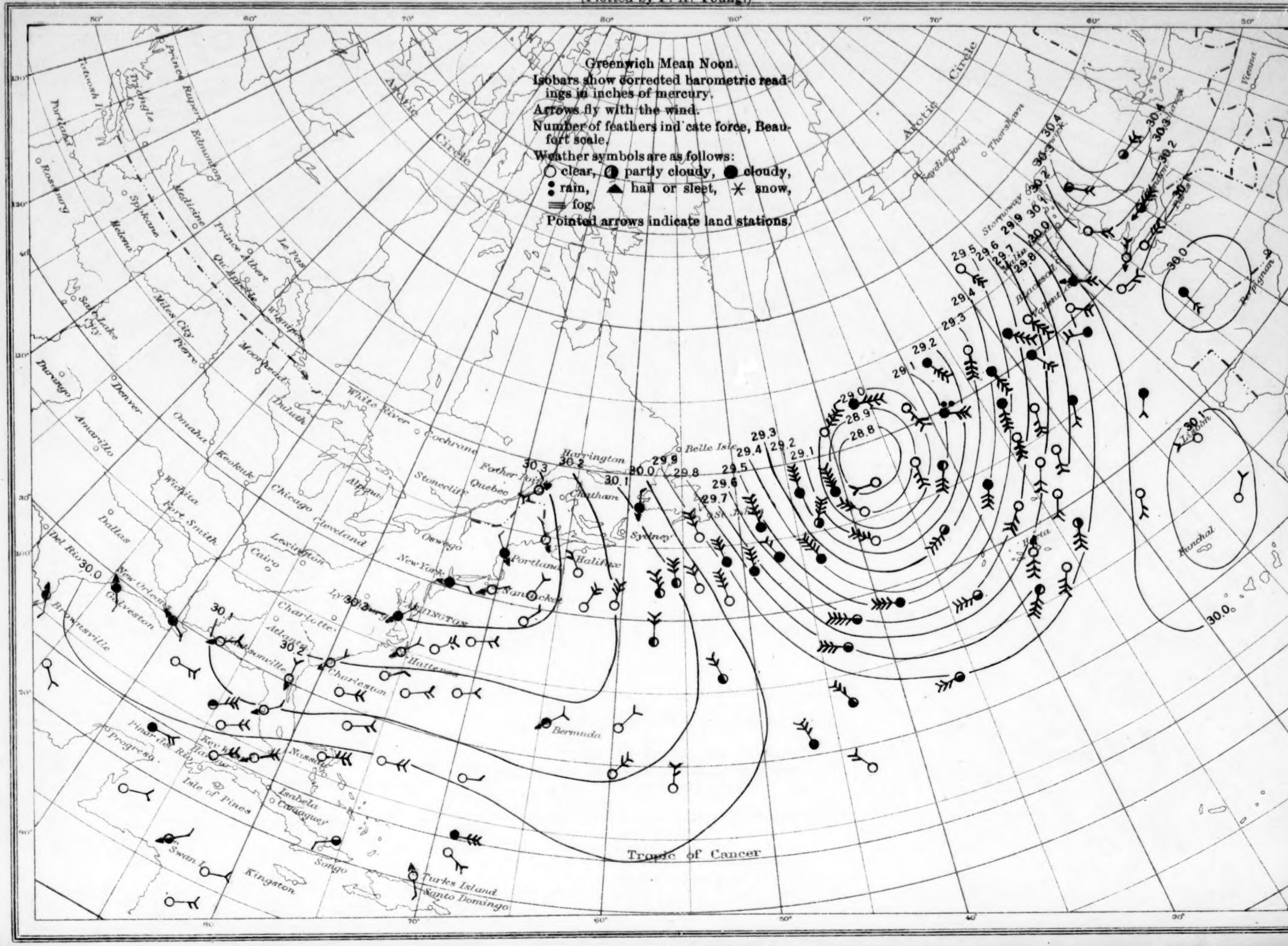


Chart XIII. Weather Map of North Atlantic Ocean, October 19, 1920.
(Plotted by F. A. Young.)

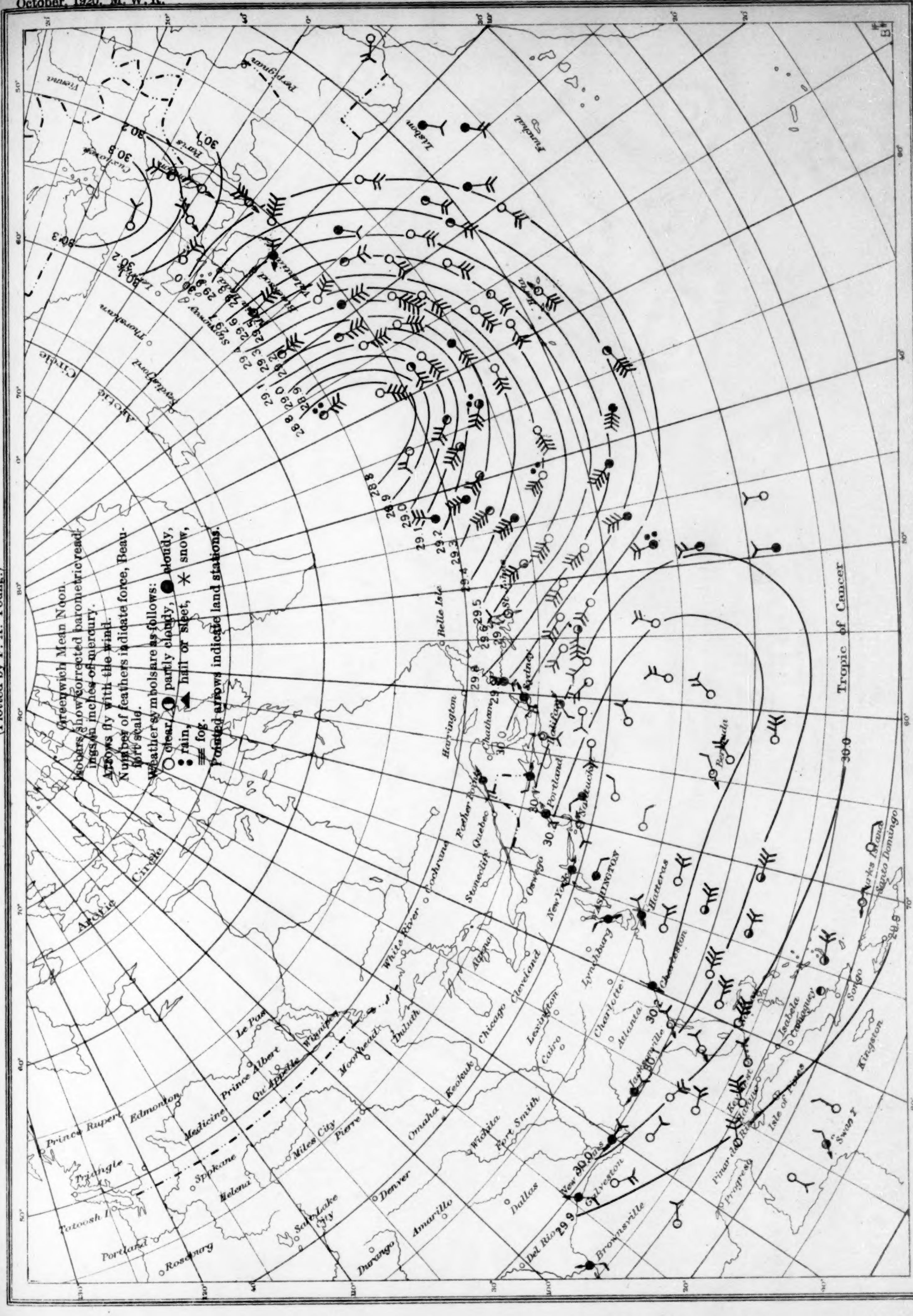


Chart XIV. Weather Map of North Atlantic Ocean, October 24, 1920.

(Plotted by F. A. Young.)